NATURAL PHILOSOPHY

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NATURAL PHILOSOPHY,

FOR

GENERAL READERS AND YOUNG PEOPLE.

TRANSLATED AND EDITED FROM

GANOT'S COURS ÉLÉMENTAIRE DE PHYSIQUE

(WITH THE AUTHOR'S SANCTION)

BY

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SIXTH EDITION.

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PREFACE.

THE present work has its origin in an attempt to comply with a suggestion which has frequently been made to me, that I should prepare an abridged edition of my translation of Ganot's *Éléments de Physique*, which could be used for purposes of more elementary instruction than that work, and in which the use of mathematical formulæ would be dispensed with. But I soon found that to do anything of the kind which would be more than a mere series of extracts would be very difficult, and hence I turned my attention to another book by the same author, which has had a very extensive circulation in France, his *Cours élémentaire de Physique*, and this I have taken as the basis of the present book.

It is not a mere translation, but such additions and alterations have been made as I thought fitted to render the book useful to the classes for which it was more especially designed—

namely, as a text-book of physics for the middle and upper classes of boys' and girls' schools, and as a familiar account of physical phenomena and laws for the general reader. In range it may, perhaps, be nearly taken to represent the amount of knowledge required for the matriculation examination of the London University.

Although English scientific literature is not wanting in works in which the main physical phenomena are explained in familiar language, they are for the most part—whether from too much conciseness in some parts or from too minute details in others, or again as being too costly—not suited for direct teaching purposes.

To facilitate reference, the articles of the present work have been numbered, and a copious index has been drawn up in accordance with this arrangement.

E. ATKINSON.

EXTRACT FROM THE

ADVERTISEMENT to the THIRD EDITION.

I HAVE ADDED an Appendix of Questions, systematically arranged in reference to the corresponding parts of the book, and designed to serve as a sort of Self-Examiner to those who have not the advantage of formal instruction.

ADVERTISEMENT to the SIXTH EDITION.

IN preparing a new edition of a work which is intended to serve only as an elementary introduction to the study of a science, the chief difficulty is that of selecting the matter to be included, for no great additions can be made without departing from the plan on which it is based. Accordingly, in the present edition I have not thought it advisable to add more than about 34 pages of new matter, and 23 additional illustrations.

E. A.

September 1887.

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ELEMENTARY COURSE
OF
NATURAL PHILOSOPHY.

BOOK I.

GENERAL PROPERTIES OF MATTER, AND UNIVERSAL ATTRACTION.

CHAPTER I.

PRELIMINARY NOTIONS.

1. **Definition of physics.**—The word *physics* is derived from the Greek φύσις, nature; for the ancients understood by the term physics the study of the whole of nature. They comprised within the domain of this science *mechanics*, *astronomy*, *chemistry*, *botany*, *zoology*, *medicine*, and even *astrology* and *divination*, whether by the stars, or by the observation of physiognomy.

The province of physics is at present much more restricted. Its object may be considered to be *the study of those phenomena which do not depend on changes in the composition of bodies*; for these belong to chemistry.

Thus, when water by cooling is changed into ice, and when this ice by being heated is again changed into water, the liquid is exactly the same as before; not merely are all its properties the same, but its volume is identical with what it originally was. The passage of water to the state of ice, and the return of the latter to the liquid state, are *physical phenomena*. In like manner, when a brittle object, one of porcelain or of glass, for instance, falls to the

ground and breaks, each piece retains exactly the same chemical composition. The fall of the vessel and its fracture against the ground are then physical phenomena.

On the other hand, when wood burns, its substance is completely modified. It consists of several different forms of matter, and is decomposed ; one part of its elements passes into the atmosphere in the form of gas and vapour, while another is left as a residue consisting of ash and charcoal. In short, the substance we know as wood has disappeared, and is replaced by others which are entirely different. The combustion of wood is accordingly a *chemical phenomenon.*

2. **Matter, mass, density.**—We understand by the term *matter* whatever can affect one or more of our senses ; that is to say, anything whose existence can be recognised by the sight, touch, taste, smell, or hearing.

The *mass* of a body is the quantity of matter contained in this body. Different substances may contain very different quantities of matter in the same volume. It will subsequently be shown, for instance, that, for equal volumes, lead contains nearly eleven times as much matter as water, and gold nineteen times as much. This is expressed by saying that the masses of lead and of gold are respectively eleven and nineteen times as *dense* as water. When one body has, for the same volume, twice or thrice the mass of another, it is said to be twice or thrice as dense, and the *density* of one substance in reference to another is the number which expresses how much matter the first body contains as compared with the second.

3. **Simple and compound substances.**—It has been ascertained that all the various forms of matter with which we are acquainted may be resolved into about sixty-five different kinds, which are called *simple substances* or *elements*, to express that each only contains one kind of matter. Many of these are very rare, and are found in very minute quantities ; others are more widely diffused, and have important uses, but are not abundant ; and the great mass of the universe is made up of about fourteen—the *non-metallic bodies*, or *metalloids*, oxygen, hydrogen, nitrogen, silicon, carbon, sulphur, phosphorus, and chlorine ; and the *metals* aluminum, potassium, sodium, calcium, magnesium, and iron.

Very few of these elements occur in nature in the free state ; by far the greater number of the substances we know are *compound* ; that is, are formed by the union of two, three, or four of these elements. Thus water consists of hydrogen and oxygen ; sand, of

silicon and oxygen; salt, of chlorine and sodium; wood, of carbon, oxygen, and calcium; marble, of carbon, oxygen, and calcium; muscular tissue, of carbon, hydrogen, oxygen, and nitrogen. The number of substances containing more than four elements is very small.

The force in virtue of which different substances unite to form compounds, and which opposes the separation of compounds into their elements, is called the force of *chemical attraction* or *affinity*.

4. **Internal constitution of bodies. Atoms, molecules, molecular forces.**—The properties of bodies prove that they are not formed of continuous and compact matter, as they seem to be, but that they are agglomerations of excessively small material particles, which are called *atoms*. The elementary atoms can unite with each other to form compounds, but cannot be destroyed by any known process.

The term *molecule* is given to the smallest cluster of atoms of any substance which is conceived to be capable of existing by itself; every pure substance consists of similar molecules.

The same properties which have led physicists to assume the existence of atoms and molecules have also led to the assumption that these small particles do not touch, but are simply juxtaposed, retaining between them extremely small intervals, which we shall afterwards become acquainted with under the name of *pores* (9).

But it may be asked, How is it that bodies do not spontaneously fall into powder? What gives them solidity and hardness? What is the invisible force that units atoms and molecules?

This force is the reciprocal attraction which the molecules of bodies exert upon each other, and which is continually drawing them together. The force which holds together particles of the *same* kind of matter is called *molecular attraction*; the force which holds together particles of *different* kinds of matter is called *chemical attraction or affinity* (3). When hydrogen and oxygen unite to form water, they do so by reason of the exercise of the latter force; while the particles of water are held together by molecular attraction.

If molecular attraction were the only force acting upon the small particles of which bodies are composed, they would come into complete contact, which is never the case. They are also under the influence of a force, in virtue of which their particles are in a constant state of motion and continually tending to separate themselves from each other; this is the force of *heat*. Experi-

ment shows, in fact, that whenever a body is heated, its volume increases because its molecules are driven apart; while on the contrary its volume diminishes when it is cooled, because the molecules then become closer. The particular form which matter assumes—whether solid, liquid, or gaseous—depends on the extent to which it is influenced by these antagonistic forces.

5. **Different states of matter.**—All substances present characters in virtue of which they may be divided into three distinct classes—*solids*, *liquids*, and *gases.*

Solids, such as wood, stones, metals, etc., are substances which are more or less hard, and retain the form which they possess naturally, or which has been given them by art. It is assumed that in solids molecular attraction preponderates over repulsion.

Liquids, such as water, oil, mercury, are bodies which have no hardness, and present but little resistance when a body is immersed in them; they have no shape of their own, but at once take that of the vessels in which they are contained; they are virtually incompressible. It is assumed that molecular attraction in them is balanced by the force of heat, and that, while the molecules can freely glide over each other, they keep an invariable distance apart if the temperature be not altered.

Gases, such as hydrogen, oxygen, carbonic acid, are also called *aëriform fluids*, from their analogy with our air, which is a mixture of oxygen and nitrogen. They are very light bodies; excepting a small number, which are coloured, they are invisible; and hence a vessel filled with air, hydrogen, or any colourless gas, appears quite empty. Like liquids, they have no shape of their own, but, unlike liquids, they are eminently compressible and expansive. In them the force of heat preponderates over molecular attraction (4); whence it follows that they are continually tending to occupy a larger space. This property will be described as the *expansibility* of gases (113).

There are many bodies which can exist in all these three different forms; thus water, exposed to great cold, becomes solid in the form of ice; at ordinary temperatures it is liquid, while at higher temperatures it becomes a gas. Sulphur, iodine, and several of the metals, such as mercury and zinc, present the same phenomena.

CHAPTER II.

GENERAL PROPERTIES OF BODIES.

6. **Extension.**—By *general properties* we understand those which are common to all bodies, whether solids, liquids, or gases; such, for instance, are *extension*, *impenetrability*, *divisibility*, *porosity*, *compressibility*, *elasticity*, *inertia*, and *gravity*.

Specific properties are such as we observe only in certain bodies, or in certain states of these bodies; *solidity*, *fluidity*, *tenacity*, *malleability*, *colour*, *hardness*, etc., are properties of this class.

The first general property of bodies with which we are concerned is their *extension* or *magnitude*; that is, the extent of space they occupy. All bodies, even the smallest atoms, have a certain extension.

Extension considered in only one direction, that of length, gives a *line*; in two directions, length and breadth, a *surface*; and, in the three directions, length, breadth, and thickness, a *volume*.

With respect to the above general properties, it may be remarked that *impenetrability* and *extension* might be more aptly termed essential attributes of matter, since they suffice to define it; and that divisibility, porosity, compressibility, and elasticity do not apply to atoms, but only to bodies or aggregates of atoms.

7. **Impenetrability.**—This is the property in virtue of which two portions of matter cannot simultaneously occupy the same portion of space. Strictly speaking, this property only applies to the atoms of bodies.

In many phenomena bodies appear to penetrate each other. Thus, if a pint of water and a pint of alcohol be mixed together, the volume of the mixture is less than two pints. A similar contraction occurs in the formation of certain alloys; for instance, brass, which is an alloy of copper and zinc, occupies a less volume than the united volumes of its constituents.

This penetration is, however, only apparent, and is due to an alteration in the position of the molecules; they come nearer each other, and the space occupied by the pores is diminished.

A nail driven into wood is not a true case of penetration. The molecules of the latter are driven apart by the nail, but wherever it has penetrated there is no wood. When water is poured upon a heap of sand it at once disappears ; the water, however, does not penetrate the substance of the sand itself, but merely fills the interstices between the grains.

When a glass tumbler is dipped into water with the mouth downwards, the volume of air inside diminishes ; this experiment proves that air is compressible, but not that it is penetrable.

If a finely drawn-out glass funnel be fitted in the neck of a bottle, water cannot be poured into the bottle, for the enclosed air cannot escape. In casting iron, the moulds must have air-holes to allow the air to escape.

8. **Divisibility.**—This is the property which all bodies have of being divided into distinct parts.

Numerous examples may be cited of the extreme divisibility of matter. The tenth part of a grain of musk will continue for years to fill a room with its odoriferous particles, and at the end of that time will scarcely be diminished in weight.

A piece of carmine not larger than a grain of corn gives a distinct colour to two gallons of water ; from which it can be deduced that this small quantity of colouring matter cannot contain less than ten million particles.

Blood is composed of red, flattened globules floating in a colourless liquid called *serum.* In man the diameter of one of these globules is less than the 3,500th part of an inch, and the drop of blood which might be suspended from a point of a needle would contain about a million of globules.

Again, the microscope has disclosed to us the existence of insects smaller even than these particles of blood ; the struggle for existence reaches even to these little creatures, for they devour still smaller ones. If blood runs in the veins of these devoured ones, how infinitesimal must be the magnitude of its component globules !

Has, then, the divisibility of matter no limit ? Although experiment fails to determine such limit, many facts in chemistry, such as the invariability in the relative weights of the elements which combine with each other, would lead us to believe that a limit does exist. It is on this account that bodies are conceived to be composed of extremely minute and indivisible parts called *atoms* (4).

9. **Porosity.**—*Pores* are the extremely small intervals which exist between the molecules of bodies, and *porosity* is the property which bodies possess of having pores.

Two kinds of pores may be distinguished: *physical* or *intermolecular* pores, where the interstices are so small that the molecules remain within the sphere of each other's attracting or repelling forces; and *sensible* pores, or actual cavities, across which these molecular forces cannot act.

The contractions and expansions resulting from variations of temperatures are due to the existence of physical pores; whilst in the organic world the sensible pores are the seat of the phenomena of exhalation and absorption.

In wood, sponge, pumice stone, and in animal and vegetable tissues, the sensible pores are apparent; physical pores never are seen. Yet since the volume of every body may be diminished, we conclude that all bodies possess physical pores.

The existence of sensible pores may be shown by the following experiment:—A long glass tube, A (fig. 1) is provided with a brass cup *m*, at the top, and a brass foot made to screw on to the plate of an air-pump. The bottom of the cup consists of a thick piece of leather. After pouring mercury into the cup so as entirely to cover the leather, the air-pump is worked, and a partial vacuum produced in the tube. By so doing, a shower of mercury is at once produced within the tube, for the atmospheric pressure on the mercury forces that liquid through the pores of the leather. In the same manner water or mercury may be forced through the pores of wood, if the leather in the above experiment be replaced by a disc of wood cut perpendicular to the fibres.

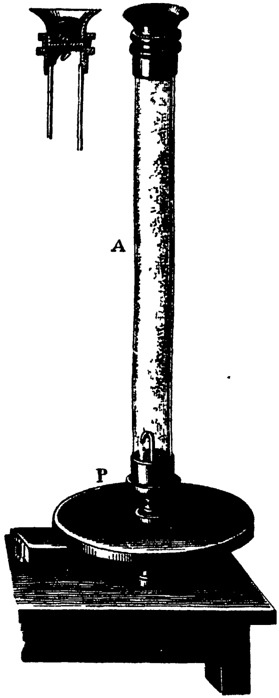


Fig. 1.

When a piece of chalk is thrown into water, air-bubbles at once

rise to the surface, in consequence of the air in the pores of the chalk being expelled by the water. The chalk will be found to be heavier after immersion than it was before, and from the increase of its weight the volume of its pores may be deduced.

The porosity of gold was demonstrated by the celebrated Florentine experiment made in 1661. Some academicians at Florence, wishing to try whether water was compressible, filled a thin globe of gold with that liquid, and, after carefully closing the orifice hermetically, they exposed the globe to pressure with a view of altering its form, knowing that any alteration in form must be accompanied by a diminution in volume. The consequence was, that the water forced its way through the pores of the gold, and stood on the outside of the globe like dew. This experiment had been made with a leaden shell twenty years before by Francis Bacon ; it has since been repeated with globes of other metals, and like results obtained.

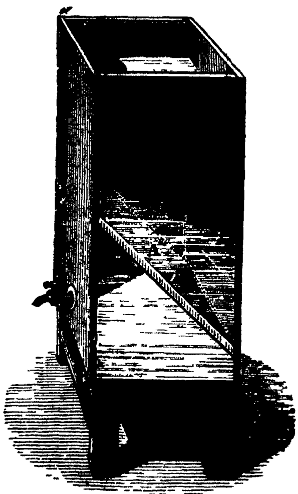


Fig. 2.

The Florentine academicians had concluded from their experiments that liquids were incompressible ; that is, could not be reduced in volume by pressure. This, however, is not the case ; liquids are compressible, though to a very small extent (75). By cooling, a far greater diminution in volume can be produced.

From these facts we conclude that the molecules of liquids may be brought nearer each other, and therefore that there are pores between them. The facility, moreover, with which liquids mix is a proof of their porosity.

10. **Applications of porosity.**—The property of porosity is frequently utilised, more especially in the process of *filtration*. This consists in clarifying liquids, by freeing them from particles of matter which they hold in suspension ; as is done, for instance, with river water, which is turbid, owing to the earthy matter it carried along with it.

The apparatus used for this purpose are called *filters*, and are usually constructed of unsized paper, felt, charcoal, etc. The pores of these substances are sufficiently large to allow liquids to pass, but small enough to arrest the particles held in suspension. Figure 2 represents a *filtering box*, one side of which is supposed to have been removed, so that its construction can be seen. It consists of a box about a yard high divided in the inside into two compartments by a porous slab, A. The water to be filtered is placed in the upper compartment, whence it slowly percolates through the pores of the stone into the lower one, leaving behind it the foreign substances. In one of the sides of the box is a tube, *a*, which terminates in the lower compartment, and allows the air to escape in proportion as water enters.

Figure 3 represents a filter known as the *strainer of Hippocrates*. It is a conical felt bag suspended by three cords, into which is poured the turbid liquor; it slowly traverses the pores, while all the solid particles to which the turbidity is due remain behind on the filter. This method is well adapted for clarifying syrups, jellies, and liqueurs.

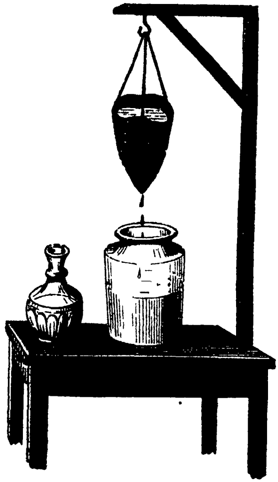


Fig. 3.

Layers of powdered wood charcoal are also used for filtration. A layer of sand or of broken glass produces the same effect. The clearness of deep well-water is due to its filtration through thick strata of earth.

11. **Compressibility.**—This is the property which bodies possess of being diminished in volume by pressure, without undergoing any loss of mass. Being due to the approach of the molecules, it is both a consequence and a proof of porosity.

Compressibility is very marked in sponge, caoutchouc, cork, pith, paper, cloth, etc. The volume of these substances is considerably diminished by mere pressure between the fingers. The compressibility of metals is proved by the impression which they receive from the die, in the process of coinage. There is, in most cases, a limit beyond which, when the pressure is increased, solids are fractured or reduced to powder.

The compressibility of liquids is so small as to have remained for a long time undetected ; it may, however, be proved by experiment, as will be seen in the chapter on HYDROSTATICS (76).

The most compressible bodies are gases, which by pressure may be made to occupy ten, twenty, or a hundred times less space than under ordinary circumstances. The great compressibility of gases may be demonstrated by means of a glass tube with very thick sides closed at one end, and provided with a tightly fitting solid piston (fig. 4). The enclosed air cannot escape, and yet, when the handle of the piston is pressed, it can be moved down to one-half to three-quarters the length of the tube; proving that the volume of the air is reduced to half or a quarter what it was originally. All gases, when thus compressed, exhibit a remarkable property, to which we shall afterwards return — that, namely, of *liquefying*, or passing from the gaseous to the liquid state.

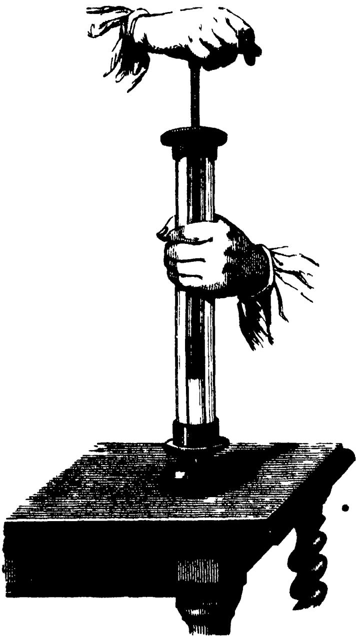


Fig. 4.

12. **Elasticity.**—*Elasticity* is the property which bodies possess of resuming their original form or volume, when, after having been compressed, bent, twisted, or pulled, the force which altered them has ceased to act.

Four kinds of elasticity may be distinguished : the elasticity by *pressure*, as in the case of gases ; the elasticity by *flexure* or *bending*, observed in springs ; the elasticity of *torsion* or *twisting*, which is developed in linen or cotton threads when they are untwisted ; and, finally, the elasticity of *tension* or *stretching*, which is that of piano or violin strings when they are stretched.

Whatever be the kind of elasticity, it is always due to a displace-

ment of the molecules. If the molecules have been brought nearer by pressure, heat tends to separate them; if, on the contrary, they have been separated, molecular attraction tends to bring them near each other again. If a piece of whalebone be bent, the molecules in the concave part, being compressed, repel each other; in the convex part, where they are separated, they tend to approach each other; both these actions concur, therefore, in straightening it as soon as it is free.

Gases and liquids are perfectly elastic; in other words, they regain exactly the same volume when the pressure becomes the same. Solid bodies present different degrees of elasticity, though none present the property in the same perfection as liquids and gases, and in all of them it varies according to the time during which the body has been exposed to pressure. Caoutchouc, ivory, glass, and marble possess considerable elasticity; lead, clay, and fats scarcely any.

There is a limit to the elasticity of solids, beyond which they either break or are incapable of regaining their original form and volume; in sprains, for instance, the elasticity of the tendons has been exceeded. India-rubber is eminently elastic; it has a wide *limit of elasticity*; it is, however, not completely elastic, for when stretched much and often it is permanently enlarged. Glass is almost perfectly elastic, but has a very narrow limit of elasticity; except in very thin strips or threads, it will not bend far without breaking. In gases and liquids, on the contrary, no such limit can be reached; they always regain their original volume, when the original condition of pressure is restored.

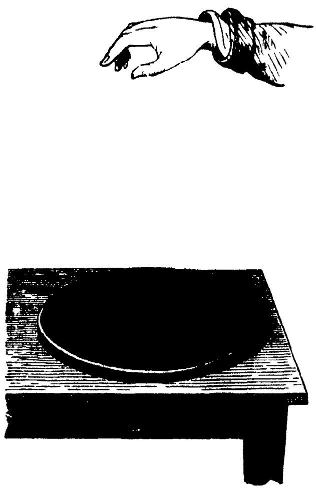


Fig. 5.

The difference between perfect and imperfect elasticity may be seen by bending two similar strips of steel and of thin wood; the steel reverts at once to its original straight line, whilst the wood is permanently curved.

The elasticity of solids may be shown by the following experiment :—On a slab of polished black marble thinly smeared with oil, an ivory ball is allowed to drop from gradually increasing heights. Each time it will rebound and rise to a height a little less than that from which it fell, after having formed on the layer of oil a circular impression which is larger the greater the height of the fall (fig. 5). From this we conclude that the ball was flattened each time, and that it rebounded in consequence of the reaction of its compressed molecules.

13. **Illustrations of elasticity.**—Numerous illustrations of the property of elasticity may be mentioned. It is owing to their elasticity that corks are used for closing bottles. When they are forcibly pushed into the neck they become compressed, and then, their elasticity causing them to press against the sides, they completely close the neck.

Children's balls depend upon the elasticity of gas : they are made of caoutchouc, and are inflated by air ; when they strike against the ground, or against a wall, their volume diminishes, and the air which they contain being suddenly compressed, expands, and, acting like a spring, makes the ball rebound. A similar application is met with in air-cushions. They are made of an air-tight material, and, being inflated by air, are both compressible and elastic, and thus form a very soft seat.

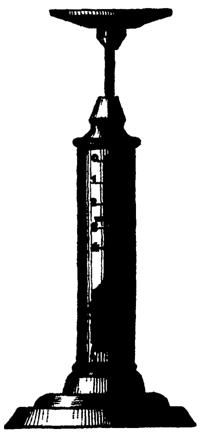


Fig. 6.

The use of carriage and of watch and clock springs depends upon the elasticity of steel. In like manner the elasticity of wool, hair, feathers, is made use of in mattresses, pillows, and seats.

The letter-weight, fig. 6, the construction of which will be at once understood, is an application of the elasticity of springs ; the dynamometer (fig. 9) also depends on the elasticity of a steel band.

Lastly, it is in consequence of their elasticity that piano, guitar, or violin strings are capable of being put into a vibratory motion, which, as we shall show, is the origin of the sounds which stringed instruments yield.

CHAPTER III.

MOTION AND FORCE.

14. **Rest and motion.**—To understand what we have to say about inertia, weight, universal gravitation, and the motion of liquids and gases, it is first of all necessary to explain some very elementary principles of motion and force.

A body is said to be at *rest* when it remains in the same place; to be in *motion* when it passes from one place to another. Both rest and motion are either absolute or relative.

Absolute rest would be the entire absence of motion. No such condition, however, is known in the universe; for the earth and the other planets rotate both about the sun and about their own axes; and therefore all the parts composing them share this double motion. Even the sun itself has a motion of rotation which excludes the idea of absolute rest.

Relative or apparent rest is the condition of a body which appears fixed in reference to surrounding objects, but which really shares with them a double motion. For instance, a passenger in a railway carriage may be in a state of relative rest with respect to the train in which he travels, but he is in a state of relative motion with respect to the objects (fields, houses, etc.) past which the train rushes. These houses, etc., again, enjoy merely a state of relative rest, for the earth itself which bears them is in a state of incessant relative motion with respect to the celestial bodies of our solar system.

The absolute motion of this passenger would be that measured in regard to a fixed point in space; this, however, cannot be realised, for we know no such point. In short, absolute motion and rest are unknown to us; in nature, relative motion and rest are alone presented to our observation.

15. **Different kinds of motion.**—Motion is either rectilinear or curvilinear: *rectilinear* when the moving body travels along a straight line, as when a body falls to the ground; *curvilinear* when

it goes along a curved line, as in the case of a horse turning in a mill.

Each kind of motion is either *uniform* or *varied.*

16. **Uniform motion.**—Motion is said to be uniform when the *moving body passes over equal spaces in equal intervals of time: such, for instance, as the motion of a water-wheel when it makes* exactly the same number of turns in a minute. Such, again, is the motion of the hand of a watch. A regiment of soldiers marching in step affords a further example of uniform motion.

The *velocity* of motion is the space traversed in a given time, a second or an hour, for example. A bullet which, fired from a gun, passes through 1,200 feet in every second, is said to have a velocity of 1,200 feet. A train which moves thirty miles in each successive hour is said to have a velocity of thirty miles an hour, or 46 feet in a second.

17. **Varied motion.**—Varied motion is that in which unequal spaces are traversed in equal times. If the spaces traversed in the same time go on increasing, the motion is said to be *accelerated*; such is the motion of a train starting from a station; if the spaces decrease, as is the case when a train comes into a station, the motion is *retarded.*

If the distances, traversed in equal times, always increase by the same amount, the motion is said to be *uniformly accelerated*; if, on the other hand, they constantly decrease by the same amount, the motion is *uniformly retarded.* We shall soon see examples of these kinds of motion in the case of falling bodies.

18. **Inertia.**—*Inertia* is a purely negative property of matter; it is the incapability of matter to change its own state of motion or of rest.

Daily observation shows that a body never spontaneously passes from a state of rest into one of motion. Bodies in falling to the ground seem to set themselves in motion. This is, however, not in consequence of any inherent property; but, as we shall afterwards see, because they are acted upon by the force of gravity.

Not merely do bodies at rest persist in a state of rest, but bodies in motion continue to move. This principle may seem less obvious than the former, because we are accustomed to see many bodies gradually move more slowly, and ultimately stop, as is the case with the billiard ball, for example. But this is not due to any inherent preference for a state of rest on the part of the billiard ball, but because the motion originally imparted to it is impeded by the

friction of the cloth on which it rolls, and by the resistance of the air. The smaller these resistances, the more prolonged is its motion; as is observed, for instance, if a ball be set rolling on a smooth sheet of ice. If all impeding causes, such as friction against the supports and the resistance of the air, were removed, a body once in motion would continue to move for ever.

19. **Effects due to inertia.**—Numerous phenomena may be explained by the inertia of matter. For instance, before leaping a ditch we run towards it, in order that the motion of our bodies at the time of leaping may add itself to the muscular effort then made.

On descending carelessly from a carriage in motion, the upper part of the body retains its motion, whilst the feet are prevented from doing so by friction against the ground; the consequence is we fall towards the moving carriage.

If a man, in running, strikes his foot against an obstacle, he is apt to fall down in front, because the rest of his body tends to retain the motion it has acquired. When a horse at full gallop suddenly stops, if the rider does not hold fast with his knees, he is thrown over the horse's head, in virtue of his inertia A grindstone only gradually acquires its full speed, but then continues its movement even after the force has ceased to act.

The terrible accidents on our railways are chiefly due to inertia. When the motion of the engine is suddenly arrested, the carriages strive to continue the motion they had acquired, and in doing so are shattered against each other.

The action of projectiles is another case. When a bullet traverses a wall, or cuts a tree in two, it is owing to its tendency to retain the velocity which the explosion of the powder had imparted to it. In the action of hammers, and of pile-driving, we have analogous cases.

The actions of beating a coat with a stick to expel dust; of shaking the snow from our shoes by kicking against the door-post; of cleaning a dusty book by striking it against another, all depend upon the property of inertia. The *hoop*, the *top*, and other toys are further illustrations.

20. **Forces, powers, resistances.**—Bodies being of themselves inert, and having no tendency to change either their state of rest or that of motion, any cause capable of making them pass from a state of rest to one of motion, or conversely from a state of motion to one of rest, is called a *force*.

The attractions and repulsions exerted between the molecules of bodies, are forces ; the muscular action which men and animals bring into play is a force, as is also the elasticity of gases and vapours, which we shall subsequently discuss.

The forces which tend to produce motion are usually called *powers* ; those which tend to destroy motion are called *resistances.* Thus, when a man drags a burden along the ground, his muscular force is a power, while the friction of the burden against the ground is a resistance.

Forces of the kind called powers are always tending to accelerate motion, and are called *accelerating forces.* Resistances, on the contrary, always tending to retard it, are called *retarding forces.*

21. **Friction.**—Suppose a wooden box A, the bottom of which is planed smooth, to be placed on a wooden table B, also smoothly polished, and that to the box is fastened a string which passes over a pulley, and to it is attached a scale-pan (fig. 7). If the box be loaded so that the total weight is 100 ounces for instance, it will be found that weights must be added to the scale-pan, until the total weight is about 50 ounces, in order to move the box in a horizontal direction along the table. If the total weight of the box be 200 ounces, the weight required to move it will be 100 ounces. If the table were a perfectly smooth polished iron plate, and the bottom of the box were shod with the same material, a weight of only thirty ounces would be sufficient to move the box.

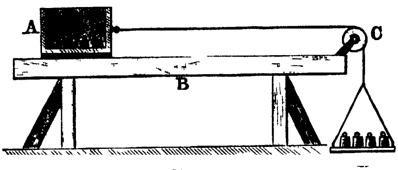


Fig 7

The resistance which is thus offered to motion is called *friction.* The surfaces of bodies are never perfectly smooth ; even the smoothest possess roughnesses which cannot be detected by the touch or by ordinary sight ; and *friction* consists in the fact that the body must be raised over these obstacles or must break them down. They fit in each other like toothed wheels.

The number which tells what proportion of the total weight must be applied simply to overcome friction is called the *coefficient of friction.* Thus the coefficient of friction between polished wooden surfaces is, as we have seen, about one-half of the weight :

between polished iron surfaces about one-third, and so on. The friction between two substances of the same kind is greater than that between two different ones which have different structures.

Friction is of two kinds : *sliding*, in which one body *slides* over another, as in the above case, or when a box is dragged along a floor ; it is least when the two surfaces are always in contact, as in the motion of an axle in its bearing ; and *rolling* friction, as when a cylindrical body moves over a horizontal surface, like an ordinary wheel on a road.

Friction is lessened by rubbing on the surfaces in contact, fatty materials which are not absorbed by them. Moisture and oil increase the friction of wood, for they are absorbed by it, while tallow, soap, and black lead lessen it. Oil and lard lessen the friction of metallic surfaces. Rolling friction is less than sliding friction, hence the use of castors on pianos and other heavy furniture. It is sometimes desirable to increase friction, as when ashes or sand are strewn on ice ; again, rolling is sometimes changed into sliding friction, in order to increase it, as when a drag is applied to a wheel. The friction of carriage wheels is less, the greater the diameter of the wheel and the less that of the axle.

Without friction on the ground neither man nor animals, neither ordinary carriages nor railway ones, could move, motion could not be transmitted by bands from one machine to another ; without it no book would remain on a desk, and without it we could hold nothing in the hands.

Gases also, and still more liquids, offer resistance to motion. If it were not for the resistance offered by the air, a hailstone half an inch in diameter falling from the height of a mile, would have a velocity of over 400 feet in a second, whereas its actual velocity is not probably more than one-twelfth of this amount.

Friction enables us to form long threads or ropes from the comparatively short fibres of cotton or hemp ; for it is the friction due to the twisted fibres which keeps the materials together.

22. **Distinctive characters of forces.**—Three things are to be distinguished in each force—the point of application, the direction, and the intensity.

The *point of application of a force* is the point at which it exerts its action. Having attached a cord to a sledge, as shown in fig. 8, the point of application is the point A, at which the cord is actually attached.

The *direction of a force* is the right line along which it urges

or tends to urge the point of application. In fig. 8 the cord AB represents the direction of the force.

The *intensity of a force* is its energy, its magnitude, or value, in reference to a certain standard. In fig. 8, which represents a horse drawing a cask on a sledge, a certain exertion of force is required on the part of the horse; if the sledge were loaded twice

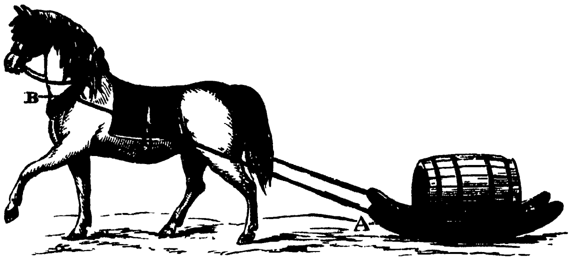


Fig. 8.

or thrice as much, the force required must be twice or thrice as great.

23. **Measurement of force. Dynamometer.**—The force which a motor (32) develops in pushing or drawing a body is measured by the number of pounds necessary to produce the same pressure or the same pull; so that a force is said to be a force of 40 or 50 pounds, when it can be replaced by the action of a weight of 40 or 50 pounds.

The weight which thus represents the intensity of a force is determined by means of the *dynamometer*. There are several forms of this instrument, one of the simplest being that represented in fig. 9. It consists of a V-shaped plate of tempered steel, AB. At one end of the arm B is fixed an iron arc, *n*, which passes freely through an aperture at the end of the arm A. To this latter is fixed an arc, *m*, fitting in the same manner in the arm B. The arc *m* is provided at the end with a crook, and *n* with a ring, and on the latter, *n*, there is a graduation obtained in the following manner:—

The apparatus being fixed to a resisting support, weights of 1, 2, 3, 4, or more pounds are successively suspended to the crook. The arm B, supported by the arc *n*, remains fixed, while the arm A, being moved by the weight attached to the arc *m*, is lowered to an extent dependent on the weight. The load is gradually increased

until it has reached the utmost limit possible without breaking, care being taken at each load to mark a line on the arc *n* at the point at which the arm A stops.

In order to apply it to the measurement of forces—to estimate for instance, the effort necessary to drag a load (fig. 10)—the crook of the arc *m* is fixed to the load, then holding in the hand the ring of the arc *n* it is pulled until the load is moved. The bending of the arm A marks on the arc *n* the value in pounds of the effort of traction.

The apparatus described is also used instead of a balance to determine the weight of bodies (fig. 9), and is known as *the steelyard.*

When forces are once measured or expressed as weights, they may be represented as to their intensity by means of a line which

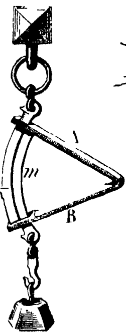


Fig. 9.

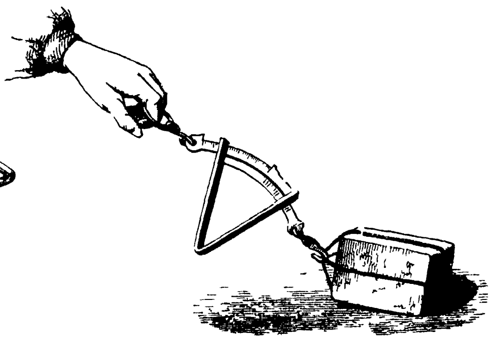


Fig. 10.

indicates their direction. For this purpose a length is measured off on this line, starting from the point of application, which contains the unit of length as many times as the intensity of the force contains pounds. Thus, if in fig. 8 the effort of traction is 15 pounds, a length, AB, would be measured from A equal to 15 times the unit of length, which may be an inch for distance. Thus the work of the horse in drawing the sledge would be represented both in direction and intensity by the line AB.

24. **Resultant and component forces.**—When a body is acted upon by only a single force, it is clear that, if it is not hindered by any obstacle, it will move in the direction of this force ; but if it is simultaneously acted upon by several forces in different directions, its direction will not, speaking generally, coincide with that of any

one of these forces. If two men, for example, on the opposite banks of a river, tow a boat by means of ropes, as shown in fig. 11, the boat follows neither the direction AB nor the direction AC, in which these men are respectively pulling, but takes an intermediate direction, AE; that is, it moves as if it were acted upon by a single force in the direction AE.

As the single force, which we conceive as having the direction

Fig. 11.

AE, produces the same effect as the forces of traction of these two men, it is called the *resultant* of these two forces; and conversely these, in reference to their resultant, are spoken of as the *components*.

25. **Value of the resultant of two concurring forces. Parallelogram of forces.**—When two forces having different directions are applied to the same point of a body, as represented in fig. 11, there is a very simple ratio between their intensities and that of their resultant, which is of great importance from the number of its applications.

It will first of all be necessary to define the word *parallelogram*, of which we shall make use. The parallelogram is a geometrical figure, formed of four right lines, each pair of which is parallel (fig. 12), that is, the two lines AB and DC are parallel, and also the lines AD and BC. These lines form the *sides* of the parallelogram, and the points A, B, C, D, the *angles*. The *diagonal* is the line like AC, joining two opposite angles A and C.

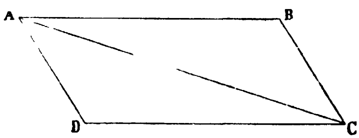


Fig. 12.

In treatise on mechanics, proofs are given of the following important theorem, which is known as the *principle of the parallelogram of forces.*

When two forces applied at the same point A (fig. 13) *are represented, in direction and in intensity, by the sides* AB *and* AD *of the parallelogram* ABCD, *their resultant is represented both as to its direction and intensity by the diagonal* AC *of this parallelogram.*

That is, that the point A being simultaneously acted upon by two forces, whose directions and intensities are respectively represented by AB and AD ; this point moves in the direction AC exactly as if it were acted upon by a single force, the direction and intensity of which are represented by the line AC.

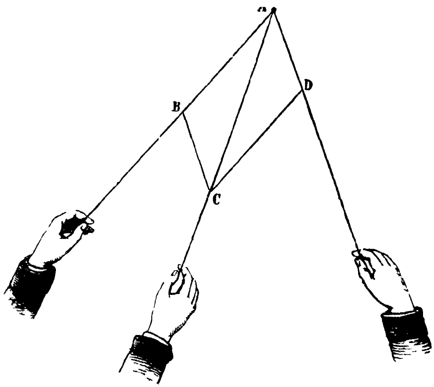


Fig. 13.

Frequent applications are met with of the principle of the parallelogram of forces. Thus, in the flight of a bird, when the wings strike against the air, a resistance is offered which is equal to impulsive forces from back to front in the directions AH and AK (fig. 14) ; hence, representing by AB and AD the intensities and directions of these impulsive forces, if the parallelogram be completed, we shall find that the resultant, or the single force which makes the bird advance, is represented in direction and magnitude by the diagonal AC. The same reasoning applies to the swimming both of men and of fishes.

26. **Another effect of the parallelogram of forces.**—We have seen that, in accordance with the principle of the parallelogram of forces, two forces applied at the same point of a body may be reduced to a single one. By the aid of the same principle a single force applied to a body may be considered to be replaced by two other forces producing together the same effect as the first. This force is then said to be *decomposed* into two others.

It is but seldom indeed that the action of a force is entirely utilised; it may almost always be considered as decomposed into two others, only one of which produces a useful effect. Thus when the wind blows against the sails of a vessel, not quite directly, but a little on one side, as shown in fig. 15, the effect of the wind in the direction *va* may be considered to be resolved into two others, one in the direction *ca*, and the other in a lateral direction *ba*, of which the first moves the vessel. The second only guides it.

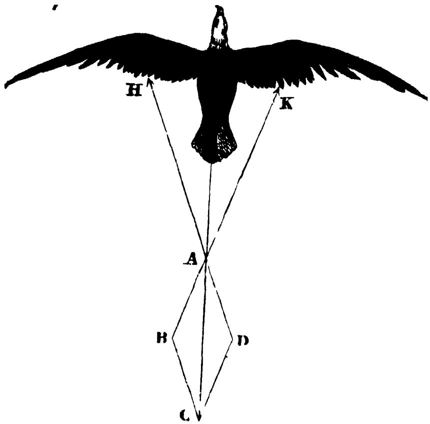


Fig. 14.

27. **Case in which the forces are parallel. Value of the resultant.**—In the case of the boat drawn by a rope (fig. 11), the forces were *concurrent*, that is, their directions if produced would

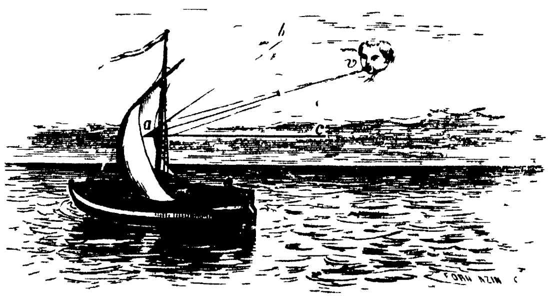


Fig 15.

meet in one point; but it may happen that the forces applied to the same body are parallel, and then two cases present themselves: that is, they either act in the same direction, as in the case of two horses drawing a carriage; or they may act in opposite directions,

when a steamer for instance ascends the river, the current acts in opposition to the force which urges the steamer. It can be proved that, in the first case, ***the resultant of the forces is equal to their sum***; and that in the second ***it is equal to their difference.***

Thus, if the speed of a Rhine steamer is 10 miles an hour, and the velocity of the current is $2\frac{1}{4}$ miles an hour, then the steamer will go ***with*** the current at the rate of $12\frac{1}{4}$ miles, and ***against*** it at the rate of $7\frac{3}{4}$ miles an hour.

28. **Equilibrium of forces.**—When several forces act upon a body at the same time, they do not always put it in motion; it may happen that while some of these forces tend to produce motion in a certain direction, the others tend to produce an equal and contrary motion in the opposite direction. It is clear that in this case, since the forces just neutralise each other, no effect can be produced. Whenever several forces applied to the same body thus mutually destroy each other, we have what is called *equilibrium.*

The simplest case of equilibrium is that of two equal and opposite forces applied at the same point of a body. For instance

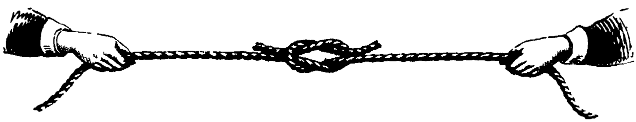


Fig. 16.

if two men pull at a cord with the same intensity, one in one direction, and the other in the opposite one, equilibrium will be produced (fig. 16). In like manner if, in a well, two buckets of the same size, each full of water, are suspended at the end of a rope which passes round a pulley, the weight of one holds the other in equilibrium.

The bodies which we consider ordinarily to be in a state of rest, are really in a state of equilibrium. For instance, when a body rests on a table, there is equilibrium between the force of gravity, which tends to make the body fall, and the resistance which the table offers to the fall. If the weight of the body exceed this resistance, equilibrium is destroyed, the table is broken, and the body falls.

29. **Centrifugal force.**—The force to which curvilinear motion, or motion in a circle, is due, is called *centrifugal force.* It may be explained as follows. Whenever a body has been put in motion

in a particular direction, owing to its inertia, it tends always to move in this direction. Hence whenever a body is seen to move in a circle, this can only be due to some obstacle, or some new force which deviates it. In fact, since a curved line may be considered to consist of a series of infinitely small straight lines, the moving body, owing to its inertia, always strives to follow the prolongation of the small straight line which it traverses at any given moment. It tends then to retain its motion in a straight line, and to fly from the curve which it is compelled to describe. This action is called the *centrifugal force*, from two Latin words which signify to fly from the centre.

The production of centrifugal force in circular motion may be demonstrated by means of the apparatus represented in fig. 17.

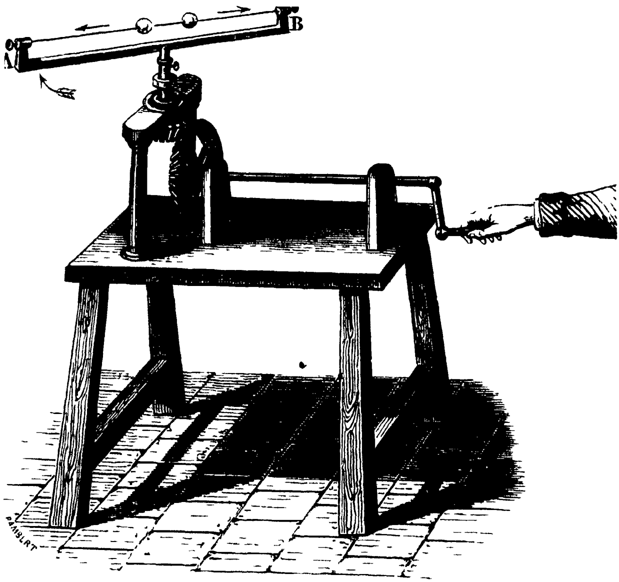


Fig. 17.

On a brass frame AB is stretched a stout brass wire, on which are slid two ivory balls which can move freely along the wire; the balls being arranged as shown in the figure, the frame is rapidly

rotated by means of the *turning-table.* The balls, projected by the centrifugal force, glide along the wire; and strike the ends with the greater force, the greater the velocity of rotation.

30. **Effects of centrifugal force.**—The centrifugal force is greater the greater the velocity, and the more marked the curvature of the line along which the movable body passes. Hence railways should be as straight as possible, for since the trains have a great velocity, as they move along a curve the centrifugal force is continually tending to throw them off, and the more so the sharper the curve.

It is owing to centrifugal force that the wheels of a carriage moving along a muddy road throw off the mud that adheres to the rim. In a circus, the horses and their riders always incline their bodies towards the centre, and the greater the speed the greater their inclination. The object of this is to allow their weight to counteract the influence of the centrifugal force which would throw them off if they stood upright.

In sugar refineries, centrifugal force is applied in removing syrups from crystallised sugar. The sugar is placed in a cylindrical vessel, whose sides are made of wire gauze, and which is put in rapid rotation. The centrifugal force scatters the coloured syrup through the meshes of the sieve, while the solid crystals are left behind colourless and pure. The same principle is applied in drying clothes in dyeworks and in large washing establishments. A wet mop made to turn quickly about its own handle as an axis throws the water off on all sides, and quickly dries itself.

A hoop trundled along the ground may move for a long time before falling; but if we attempt to keep it upright while in a state of rest, it at once falls. The reason of this is that, while in motion, if it inclines to one side, the inclination causes it to describe a curved line, whence arises a centrifugal force which opposes the fall of the hoop, at any rate so long as it retains a sufficient velocity.

31. **Flattening of the earth at the poles.**—One of the most remarkable effects of centrifugal force is the flattening of the earth at the two poles. To explain this phenomenon we must premise that the earth, which is nearly spherical in form, rotates about an imaginary axis passing through its two poles, and that in this rotation all points on the surface have not the same velocity, seeing that they do not describe the same paths in the same time. For, at the equator, they describe every twenty-four hours a circumfer-

ence equal to that of the earth ; on the other hand, points taken at increasing distances from the equator gradually describe smaller and smaller circles, while points at the poles have no such motion. Hence, owing to the daily rotation about the earth's axis, a centrifugal force is produced which is greatest at the equator, and gradually diminishes up to the poles, where there is none at all. Owing to this inequality in the intensity of the centrifugal force, there must arise an accumulation of matter about the equator, especially if, as geologists assume, the earth was originally in a state of fusion.

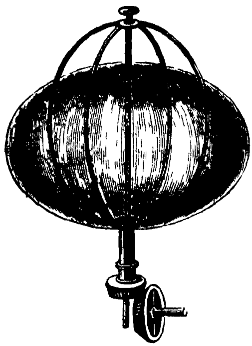


Fig. 18.

It has, in fact, been ascertained by direct determination (63) that the radius of the earth at the poles is less than that at the equator by about $\frac{1}{289}$ the latter, or $13\frac{1}{2}$ miles. A similar flattening has been observed in other planets.

To demonstrate this bulging at the equator and flattening at the poles, use is made of the apparatus represented in fig. 18. It consists of an iron rod, which may be fixed upon a turning-table, instead of the piece AB (fig. 17). At the bottom of the rod are fixed four thin elastic metal strips, which are joined at the top to a ring which can slide up and down the rod. The apparatus being then put in rapid rotation, the upper ring slides down the rod, to an extent depending on the rapidity of the rotation, and if this is sufficiently rapid the separate impressions of the individual strips coalesce into one which presents the appearance of a solid ellipsoidal figure.

LEVERS.

32. **Mechanics. Machines.**—*Mechanics* is the science which treats of forces and of motion. Several forces being applied to the same body, it indicates the relation which must exist between them in order to produce equilibrium, or in order to produce a given effect.

Any apparatus which serves to transmit the action of a force is a *machine* ; and any force which moves a machine is a *motor*. In cutting an apple with a knife, the hand is the motor, and the knife which transmits its action is a machine. A horse drawing a cart is

a motor, and the cart which utilises the force of the horse in conveying loads is a machine. The watercourse which works a wheel, the wind which turns a mill, and the steam which moves a locomotive, are all motors; and the water-wheel, the windmill, and the locomotive are all machines.

Machines do not increase the force of a motor. The useful effect of a machine can never exceed that of the mechanical force applied to it; whatever is apparently gained in force by a machine is lost in distance or in time; by modifying the action of the power, however, they render it capable of performing work which it alone could not do. For instance, by the aid of a lever, a man can raise burdens which without such help would be quite impossible. We shall only describe here the lever, the simplest of all machines, and shall afterwards see its action in the case of balances.

33. **Levers.**—A lever is a rigid bar of wood or of metal moveable about a fixed point or edge called the *fulcrum*; and subject to the action of two forces which tend to move it in opposite directions. The force which acts as motor is called the *power*, and the other the *resistance*. Levers are divided into three classes, according to the different positions of the power, and resistance, in reference to the fulcrum.

A lever of the first kind is one in which the fulcrum is between the power and the resistance. Fig. 19 represents one of this kind

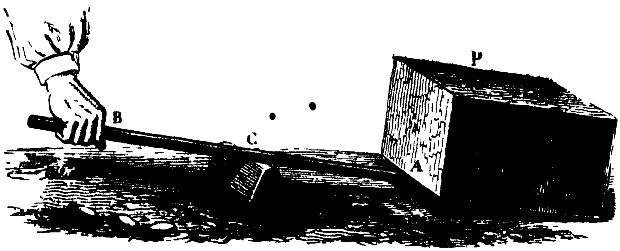


Fig. 19.

in which the hand is the power B, the weight P the resistance, while C is the fulcrum.

A lever of the second kind has the resistance between the power and the fulcrum as in fig. 20.

A lever of the third kind is one in which the power is applied between the resistance and the fulcrum, as represented in fig. 21.

In these different kind of levers, the distances from the fulcrum to the power and to the resistance are called the *arms of the lever.* In fig. 19, for instance, the arm of the power is the distance from C to B, and that from C to A is the arm of the resistance.

34. **Effect of levers. Condition of equilibrium.**—It may be shown that the effect produced by a force by means of a lever increases with the length of the arm upon which it acts: that is, if the arm is twice, thrice, or four times as long, the useful effect is two, three, or four times as great. This is what led Archimedes to say that, give him a fulcrum, and he would lift the world.

Since a force produces a greater effect the longer the arm of the lever, it follows that in order to produce equilibrium between

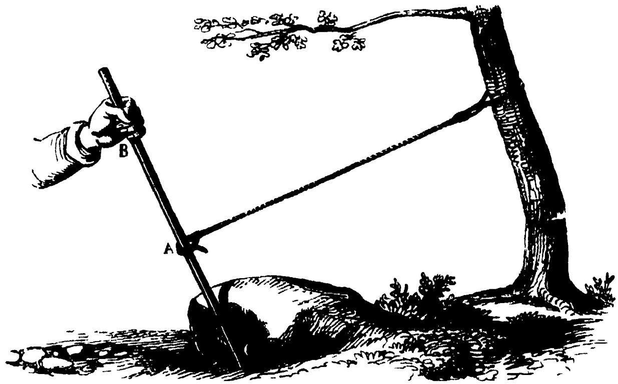


Fig. 20.

the power and the resistance, acting at the same time on a lever, if the arms are equal, *the two forces themselves must be equal*, and that if the arms of the lever are unequal, *the two forces must be inversely as the arms of the lever*; thus, if the power is one-third that of the resistance, the arm of the power should be three times as long as that of the resistance.

In a lever of the third kind the power must be always greater than the resistance, for the distance of the resistance P from the fulcrum AC (fig. 21) is always greater than the distance BC from the power B to the fulcrum. In a lever of the second kind the power is always smaller than the resistance, for the arm BC is longer than the arm AC (fig. 20). These properties are expressed

by saying that, in a lever of the third kind there is a loss of power, and in one of the second kind a gain. In a lever of the first kind there may be either gain or loss, or they may just balance each

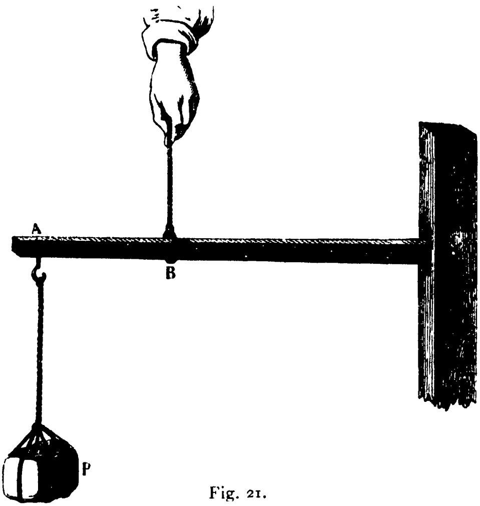


Fig. 21.

other, for the arm BC of the power (fig. 19) must be either greater or less, than, or equal to, the arm AC.

35. **Various applications of levers.**—Numerous applications of the different kinds of levers are met with in articles of everyday use. The ordinary balance (fig. 36) is a lever of the first kind, as is also a pump

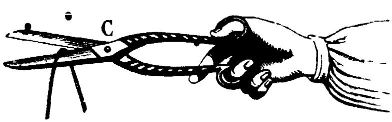


Fig. 22.

handle. Scissors are another instance ; each handle is a lever, the fulcrum of which is the pivot C ; the power is the hand, and the resistance is the material to be cut (fig. 22).

As levers of the second class may be enumerated the oars of a boat ; the resistance of the water to the motion of a feather of the oar represents the fulcrum, the hand of the oarsman is the power, and the boat, or rather the water it displaces, is the resistance. The knife fixed at one end and used in slicing roots, or cutting

bread, is a lever of the second kind. Nutcrackers (fig. 23) afford a third illustration, as also does the common wheelbarrow.

When two porters carry on a pole a load placed midway between them, they share it equally, that is, each bears half, for the pole becomes a lever, of which each porter is a fulcrum as regards the other ; but if the load be nearer one than the other, he to whom it is nearer bears proportionally more of its weight.

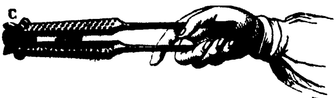


Fig. 23.

The consideration of this kind of lever explains why a finger, caught near the hinge of a shutting door, is so severely crushed.

The third kind of lever is less frequently met with. The pedals used in pianos and in grindstones are instances. In the latter case the pedal consists of a wooden board AC (fig. 24) forming a lever. The fulcrum is at C on a bolt fixed to the frame ; the power is the foot of the man turning, and the resistance, which is the motion to be transmitted to the wheel, is applied at A by means of a rod joined to a crank in the centre of the stone.

Fig. 24.

In the common fire-tongs each leg is a lever of the third kind. The hand of a man pushing open a gate while standing near the hinges moves through much less space than the end of the gate, and must exert, therefore, a proportionally greater force.

The most beautiful and numerous instances are met with in the muscular system of men and animals, almost all motions of which are affected by this mechanism.

CHAPTER IV.

GRAVITATION.

36. **Universal attraction.**—It is stated that Newton, sitting one day in his garden, and seeing an apple fall from a tree, was led by this circumstance to reflect upon the cause why bodies fell to the ground, and ultimately to the discovery of the important laws which govern the motion of the earth and of the stars.

They may be thus stated :—

1. *All bodies in nature exert a mutual attraction upon each other at all distances, in virtue of which they are continually tending towards each other.*

2. *For the same distance the attractions between bodies are proportional to their masses.*

3. *The masses being equal, the attraction varies with the distance, being inversely proportional to the square of the distances asunder.*

To illustrate this, we may take the case of two spheres, which attract each other just as if their masses were concentrated in their centres. If without other alteration the mass of one sphere were doubled, trebled, etc., the attraction between them would be doubled, trebled, etc. If, however, the mass of one sphere being doubled, that of the other were increased three times, the distance between their centres remaining the same, the attraction would be increased six times. Lastly, if, without altering their masses, the distance between their centres were *increased* from 1 to 2, 3, 4, . . . units, the attraction would be diminished to the 4th, 9th, 16th . . . part of its former intensity.

37. **Gravitation.**—The term *gravitation* is applied more especially to the attraction exerted between the heavenly bodies. The sun, being that member of our planetary system which has the largest mass, exerts also the greatest attraction, from which it might seem that the earth and the other planets ought to fall into the sun in virtue of this attraction. This would indeed be the case, if they were only acted upon by the force of gravitation ; but, owing

to their inertia, the original impulse, which they once received, constantly tends to carry them away from the sun in a straight line. The resultant of this acquired velocity, and of the force of gravitation, makes the planets describe curves about the sun which are almost circular, and are called their *orbits*.

38. **Gravity.**—This is the force in virtue of which bodies *fall* when they are no longer supported, that is, tend towards the centre of the earth. It is a *particular case* of universal attraction; and is due to the reciprocal attraction exerted between the earth and bodies placed on its surface; it acts equally upon all bodies, whether they are at rest or in motion; whether they are solids, liquids, or gases. Some bodies, such as clouds and smoke, appear not to be influenced by this force, for they rise in the atmosphere instead of sinking; yet this, as will afterwards be seen, is no exception to the action of gravity (155).

Gravity, being a particular case of universal attraction, acts upon bodies proportionally to their mass and inversely as the square of their distance; that is, a body which contains twice or thrice as much matter as another, is attracted by the earth with a twofold or threefold force; or, in other words, weighs twice or thrice as much. In like manner if one and the same body could be moved to twice or thrice its present distance from the *centre* of the earth, it would have one-fourth or one-ninth of its present weight; we say the *centre* and not the *surface* of the earth, for it is demonstrated in treatises on mechanics that the attractive force of the earth which causes bodies to fall must be calculated from its centre.

From the magnitude of the earth's radius, which is about 4,000 miles, all bodies on its surface may be considered to be virtually at the same distance from the centre, and we may therefore conclude that their difference in weight is merely due to their difference in mass.

39. **The weight of a body increases from the equator to the poles.**—The magnitude of the force which makes bodies fall is not exactly the same at all points of the earth's surface. Two causes make it increase from the equator to the poles: the daily rotation of the earth about its axis, and the flattening at the poles. For the rotation of the earth gives rise to a centrifugal force acting from the centre to the surface, that is, in the opposite direction to the force of gravity. Hence bodies are continually acted upon by two forces in opposite directions; the force of gravity, which draws them towards the centre, and the centrifugal force, which tends to drive

them away from it. So that it is really the excess of the first force over the second which makes bodies fall. But as the centrifugal force decreases from the equator towards the poles (31), the excess of gravity over this force becomes greater, and thus the weights of bodies increase as they come nearer the poles.

The flattening of the earth concurs in producing the same effect; for, in consequence of it, bodies placed on the surface of the earth are nearer the centre at the poles than they are at the equator, and are therefore more attracted. It must be added, that the increase in weight due to the joint effect of these two causes is very small; it cannot be detected by ordinary balances, for gravity would act both on the weight and on the body to be weighed. A body suspended, however, to a delicate spring balance, would indicate slightly different weights, according as it was nearer or further from the poles.

40. **Vertical and horizontal lines.**—At any point of the earth's surface, the direction of gravity, that is, the line which a falling body describes, is called the *vertical* line. The vertical lines drawn at different points of the earth's surface converge very nearly to the earth's centre. Hence, owing to the great distance from the surface of the earth to its centre, these verticals may be assumed

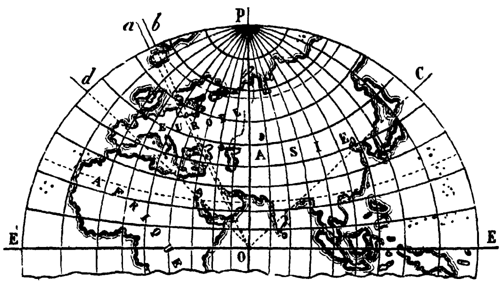


Fig. 25.

to be parallel for points on the surface *a* and *b* (fig. 25), not far apart; but they are less parallel the further apart the points, as shown by the verticals *a* and *d*. For points situated on the same meridian the angle contained between the vertical lines equals the difference between the *latitudes* of those points.

At each point on the surface of the earth a man standing

upright is in the direction of the vertical. But, as we have just seen, this direction changes from one place to another, and the same is the case with the position of the inhabitants of the various countries on the earth. As the earth is spherical, it follows that at two points, exactly opposite, two men will be in inverted positions in reference to each other; from which is derived the term *antipodes* (opposite as regards the feet), given to the inhabitants of two diametrically opposite places.

A plane or a line is said to be *horizontal* when it is perpendicular to the direction of the vertical. The surface of water in a state of equilibrium is always horizontal. In speaking of the *level* (92) we shall learn how the horizontality of any surface or line is determined.

41. **Plumb-line.**—The vertical line at any point of the globe is generally determined by the *plumb-line* or *plummet* (fig. 26), which

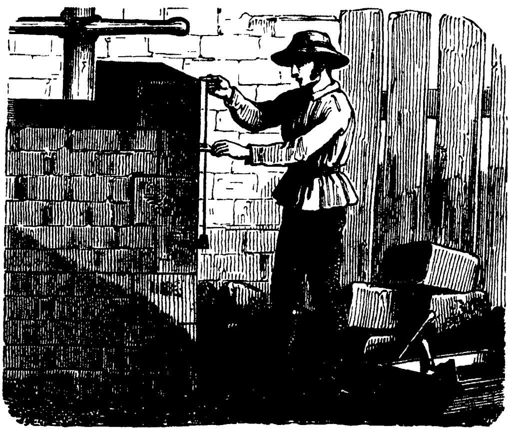


Fig. 26.

consists of a cylindrical weight attached to the end of a string. In obedience to the action of gravity this weight draws the string in the direction of this force, and when it is at rest the string is in the vertical direction. To ascertain by aid of the plumb-line whether a given surface, a wall for example, is vertical, a small metal plate is used, the side of which is equal to the diameter of the weight. In the centre of this plate is a small hole through which passes the

string: holding in one hand the plate, and in the other the string, the edge of the plate is pressed against the wall (fig. 26); if the weight just touches it the wall is vertical; if the cylinder does not touch the wall, it shows that the wall is inclined inwards; it is inclined outwards if the weight touches the wall when the plate is a little removed from it.

42. **Weight of a body.**—The *weight* of a body is the sum of the partial attractions which the earth exerts upon each of its molecules. Hence the weight of a body must increase as its mass does; that is, if it contains twice or thrice as much matter, its weight must be twice or thrice as great. The weight of a body is not to be confounded with *gravity*; this is the cause which produces the fall of bodies; the weight is only the effect. We shall presently see how weight is determined by means of the balance; gravity is measured by the aid of the pendulum.

43. **Centre of gravity.**—We have seen that all the partial attractions which the earth exerts upon each of the molecules of a body are equivalent to a single force, which is the weight of the body. Now, it may be shown in mechanics that, whatever be the shape of any body, there is always a certain point through which this single force, the weight, acts, in whatever position the body be placed in respect to the earth; this point is called *the centre of gravity* of the body.

To find the centre of gravity of a body is a purely geometrical problem; in many cases, however, it can be at once determined. For instance, the centre of gravity of a right line is the point which bisects its length; in the circle and sphere it coincides with the geometrical centre; in cylindrical bars it is the middle point of the axis; in a square or a parallelogram it is at the point of intersection of the two diagonals. These rules, it must be remembered, presuppose that the several bodies are of uniform density.

44. **Experimental determination of the centre of gravity.**—The centre of gravity of a body may also be found by experiment. When its weight is not too great, it is suspended by a string in two different positions; the centre of gravity of the body is necessarily below the point of suspension, and therefore in the prolongation of the vertical cord which sustains it. If then, in two different positions, the vertical lines of suspension be prolonged, they cut one another, and the point of intersection is the centre of gravity sought.

In the case of thin flat substances, like a piece of cardboard or

a sheet of tin plate, the centre of gravity may be found by balancing the body in two different positions on a horizontal edge; for instance, sliding them near the edge of a table until they are ready to turn in either direction (fig. 27). The centre of gravity is then on the line *ab*. Seeking, in a similar manner, a second position of equilibrium in which the line of contact is *cd* for instance, the centre of gravity must necessarily be on both these lines, that is, must be at the point of their intersection, *g*: or, more accurately, a little below this point, in the interior of the body, and at an equal distance from its two faces.

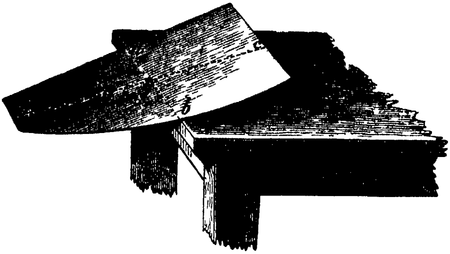


Fig. 27.

If the body be thicker, three positions of equilibrium must be found; the centre of gravity is then at the point of intersection of the three planes passing vertically through the lines of contact when the body is in equilibrium.

Fig. 28.

45. **Equilibrium of heavy bodies.**—As the centre of gravity is the point where the whole action of gravity is concentrated, it follows that whenever this point rests upon any support, the action of gravity is destroyed, and therefore the body remains in equilibrium. There are, however, several cases, according as the body has one or more points of support.

Where the body has only one point of support equilibrium is

only possible when the centre of gravity either coincides with this point or is exactly above or below it in the same vertical line; for then the action of gravity is destroyed by the resistance of the fixed point through which this force passes. The plumb-line (fig. 26) is a case of this kind, the centre of gravity being below the point of support. Another example is the case of a stick balanced on the finger, as seen in fig. 28, in which the letter *g* indicates the position of equilibrium exactly over the point of support.

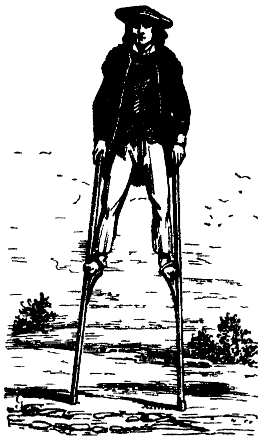


Fig. 29.

If the body has two points of support, it is not necessary for equilibrium that its centre of gravity coincide with either of these points, or be exactly above or below: it is sufficient if it be exactly below or above the right line which joins these two points, for the action of gravity may then be decomposed into two forces applied at the points of support, and destroyed by the resistance of these points. A man on stilts (fig. 29) is an example of this case of equilibrium.

Fig. 30.

Lastly, if a body rests on the ground by three or more points of support (fig. 30), equilibrium is produced whenever the centre of gravity is within the *base* formed by these points of support; that is, whenever the vertical let fall from the centre of gravity to the earth is within the points of support; for gravity cannot then overturn the body beyond its points of support, and its only effect is to settle it more firmly on the ground.

46. **Different states of equilibrium.**—Although a body supported by a fixed point is in equilibrium whenever its centre of gravity is in the vertical line through that point, the fact that the

centre of gravity is always tending to occupy the lowest possible position leads us to distinguish between three states of equilibrium —*stable*, *unstable*, *neutral.*

A body is said to be in *stable equilibrium* if it tends to return to its first position after the equilibrium has been slightly disturbed. Every body is in this state when its position is such that the slightest alteration of the same elevates its centre of gravity; for the centre of gravity will descend again when permitted, and after a few oscillations the body will return to its original position.

The pendulum of a clock continually oscillates about its position of stable equilibrium, and an egg on a level table is in this state when its long axis is horizontal. We have another illustration in the toy represented in fig. 31.

Fig 31

These little figures, which are hollow and light, are loaded at the base with a small mass of lead, so that the centre of gravity is very low. Hence when the figure is inclined, the centre of gravity is raised, and gravity tending to make it descend, the figure reverts to its original position after a number of oscillations on the right and left of its final position of equilibrium.

A body is said to be in *unstable equilibrium* when, after the slightest disturbance, it tends to depart still more from its original position. A body is in this state when its centre of gravity is vertically above the point of support, or higher than it would be in any adjacent position of the body. An egg standing on its end, or a stick balanced upright on the finger, is in this state (fig. 28). As soon as the stick is out of the vertical its centre of gravity descends, and, gravity acting with increasing force, the stick falls,

if care be not taken to bring the point of support below the centre of gravity, by which equilibrium is restored.

Neutral equilibrium.—A body is in a state of neutral equilibrium when it remains at rest in any position which may be given to it. This can only be the case when an alteration in the position of the body neither raises nor lowers its centre of gravity. A perfect sphere resting on a horizontal plane is in this state.

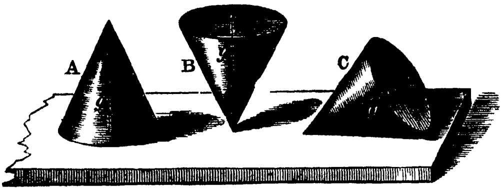


Fig 32

Fig. 32 represents three cones A, B, C, placed respectively in stable, unstable, and neutral equilibrium upon a horizontal plane. The letter *g* in each shows the position of the centre of gravity.

47. **Examples of stable equilibrium.**—It follows, from what has been said, that the wider the base on which a body rests, the greater is its stability; for then, even with a considerable inclination, its centre of gravity falls within its base.

The well-known leaning towers of Pisa and Bologna are so much out of the vertical that they seem ready to fall at any moment; and yet they have remained for centuries in their present position, because the perpendiculars let fall from their centres of gravity are within the base. Fig. 33 represents the tower of Bologna, built in the year 1112, and known as the *Garisenda.* Its height is 165 feet, and it is 7 or 8 feet out of the vertical. The leaning is due to the foundations having given way. The tower on the side is that of Asarelli, the highest in Italy.

In the cases we have hitherto considered, the position of the centre of gravity is fixed; this is not the case with men and animals, whose centre of gravity is continually varying with their attitudes, and with the loads they support.

When a man, not carrying anything, stands upright, his centre of gravity is about the middle of the lower part of the pelvis, that is, between the two thigh-bones. This, however, is not the case with a man carrying a load, for, his own weight being added to that

of the load, the common centre of gravity is neither that of the man nor of his burden.

In this case, in order to retain his stability, the man must so modify his attitude as to keep his centre of gravity directly above the base formed by his two feet. Thus a porter with a load on his back is obliged to lean forward (fig. 34); while a man carrying a load in one hand is obliged to lean his body on the opposite side (fig. 35).

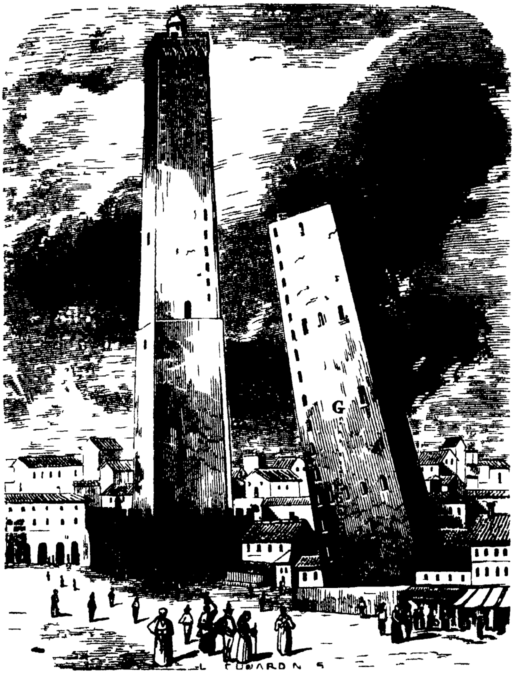


Fig 33

Again, it is impossible to stand on one leg if we keep one side of the foot and head close to a vertical wall, because the latter prevents us from throwing the body's centre of gravity vertically above the supporting base.

In the art of rope-dancing the difficulty consists in maintaining

the centre of gravity exactly above the rope. In order more easily to accomplish this, the performer holds in his hands a long pole, which, as soon as he feels himself leaning on one side, he inclines towards the opposite one; and thus contrives to keep the centre of gravity common to himself and to the pole, in a vertical line above the rope, and so preserves his equilibrium.

A broad waggon is more stable than a narrow one; and in loading a waggon, the heaviest goods should be in the bottom of the waggon, so that the centre of gravity of the whole may be as low as possible.

A boat is more easily upset when a person stands up in it than when he is seated.

48. **The balance.**—The balance is an instrument for determining the *relative* weights or rather masses of bodies.

Fig 34. Fig. 35.

The ordinary balance (fig. 36) consists of a lever of the first kind, called the *beam* AB, with its fulcrum in the middle; at the extremities of the beam are suspended two *scale-pans*, D and C; one intended to receive the object to be weighed, and the other the counterpoise. The fulcrum consists of a steel prism, *n*, commonly called a *knife-edge*, which passes through the beam, and rests with its sharp edge, or *axis of suspension*, upon two supports; these are formed of agate or of polished steel, in order to diminish the friction. A needle or pointer is fixed to the beam, and oscillates with it in front of a fixed graduated arc; when the beam is perfectly horizontal, the needle points to the zero of the graduated arc.

Since (34) two equal forces in a lever of the first kind cannot be in equilibrium unless their leverages are equal, the length of the arms *n*A and *n*B ought to remain equal during the process of weighing. To secure this, the scales are suspended from hooks, whose curved parts have sharp edges, and rest on similar edges at the ends of the beam. In this manner the scales are supported on what are practically mere lines, which remain unmoved during the oscillations of the beam. This mode of suspension is represented in fig. 36.

The weight of any body is determined by placing it in one of

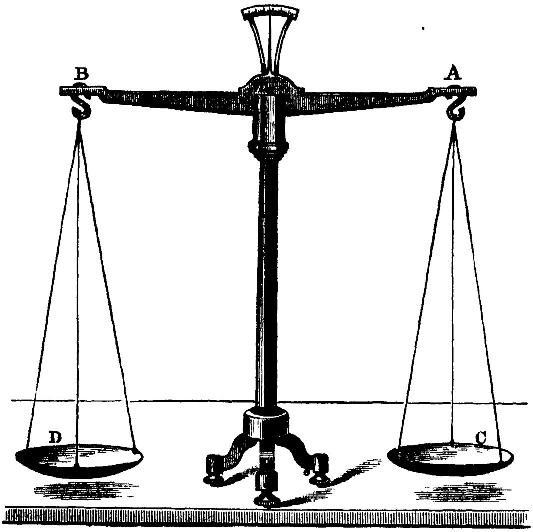


Fig. 36.

the pans of the balance, D, for instance, and adding weights to the other until equilibrium is established, which is the case when the beam is quite horizontal.

49. **Conditions to be satisfied by a good balance.**—A good balance should be *accurate*: that is, it should give exactly the weight of a body; it should also be *delicate*: that is, the beam should be inclined by a very small difference between the weights in the two scales.

Conditions of accuracy. i. *The two arms of the beam ought to*

be precisely equal; otherwise, according to the principle of the lever (34), unequal weights will be required to produce equilibrium. To test whether the arms of the beam are equal, weights are placed in the two scales until the beam becomes horizontal; the contents of the scales being then interchanged, the beam will remain horizontal if its arms are equal, but if not, it will descend on the side of the longer arm.

ii. *The balance ought to be in equilibrium when the scales are empty*; for, otherwise, unequal weights must be placed in the scales in order to produce equilibrium. It must be borne in mind, however, that the arms are not necessarily equal, even if the beam remains horizontal when the scales are empty; for this result might also be produced by giving to the longer arm the lighter scale.

iii. *The beam being horizontal, its centre of gravity ought to be in the same vertical line with the edge of the fulcrum, and a little below the latter.* For if the centre of gravity coincided with this line, the action of gravity on the beam would be null, and it would not oscillate. If the centre of gravity were above the edge of the fulcrum, the beam would be in unstable equilibrium; while, if it is below the fulcrum, the weight of the beam is continually tending to bring it back to the horizontal position as soon as it diverges from it, and the balance oscillates with regularity.

Conditions of delicacy. (1) *The centre of gravity of the beam should be very near the knife-edge*; for then, when the beam is inclined, its weight only acting upon a short arm of the lever, offers but little resistance to the excess of weight in one of the pans.

(2) *The beam should be light*; for the friction of the knife-edge upon the supports is smaller the less the pressure. In order more effectually to diminish friction, the edges from which the beam and scales are suspended are made as sharp as possible, and the supports on which they rest are very hard.

(3) Lastly, *the longer the beam the more delicate is the balance*; because the difference in the weights in the pans then acts upon a longer arm of the lever.

50. **Method of double weighing.**—Notwithstanding the inaccuracy of a balance, the true weight of a body may always be determined by its means. To do so, the body to be weighed is placed in one scale, and shot or sand poured into the other until equilibrium is produced; the body is then replaced by known weights until equilibrium is re-established. The sum of these

weights will necessarily be equal to the weight of the body, for, acting under precisely the same circumstances, both have produced precisely the same effect.

51. **The steelyard.**—A form of this instrument, different from that already described (23), is an application of the principle of the lever of the first kind (33). The fulcrum (fig. 37) is at C, and the weight, P, is suspended at A so that it acts along the short arm of the lever AC. The longer arm, BC, is graduated into equal parts, and the weight, Q, with its ring-formed knife-edge, D, is moved along the sharp edge of this arm until a position is found in which it just counterbalances the load. It follows from the principle of

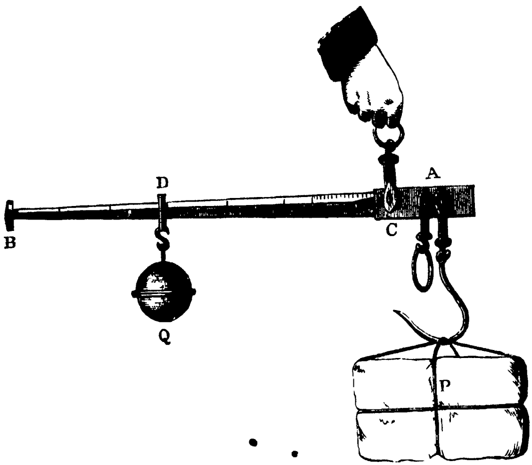


Fig 37.

the lever that the smaller weight acting through the longer distance, BC, is equivalent to the greater weight acting through the shorter distance, AC.

52. **Weighing machines.**—One of the forms of these instruments, which are of frequent use in railway stations, coal yards, &c., for weighing heavy loads, is represented in fig. 38. It consists of a platform, A, on which the body to be weighed is placed, and to which an upright, B, is fixed ; the whole rests on a frame, HE, by the following mode of suspension.

To the upright, E, are adapted two pieces of iron, which support a beam, LR, by the aid of a knife-edge, which traverses it at O.

The two arms of the beam are unequal in length; one of them supports a scale, D, in which are placed the weights; the other arm of the beam has two rods, by which is suspended the movable part, AB. In order to relieve the knife-edge which supports the platform, and to avoid a shock when it is unloaded, after a weighing has been made, the arm, OR, is lifted by raising a support, *r*,

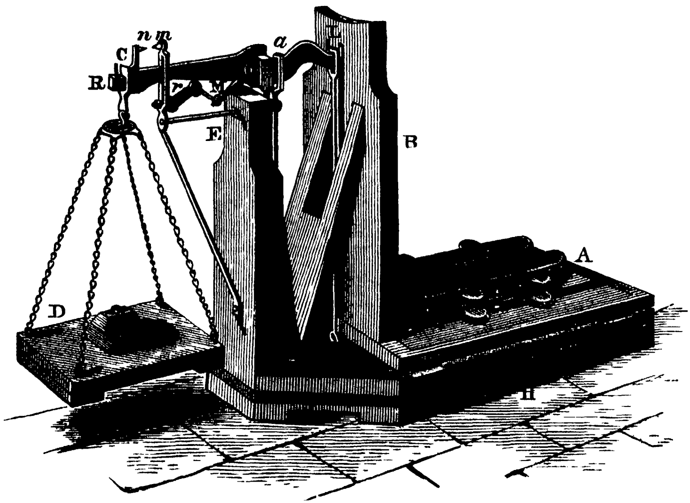


Fig. 38.

which is below the beam, by means of the handle, M. The horizontality of the beam is ascertained by means of two indicators, *m* and *n*, the first fixed to the frame and the second to the beam.

To understand the working of the mechanism reference must be made to fig. 39, in which the principal parts only are represented. A lever, *ih*, which bifurcates underneath the platform, rests at one end on a double knife-edge, *i*, and at the other on the lower end of the rod, L*h*, which is fixed to the beam. A second lever, *eg*, rests at *s* on the lever *ih*, attached at *g* to the rod *ag*, which is also supported by the beam. Lastly, the distance *is* being the fifth of *ih*, *aO* is also a fifth of OL.

From this division of the two levers, *ih* and OL, into proportional parts, two important consequences follow. First, that, when

the beam oscillates, the points *a* and *g* being lowered by a certain amount, the points L and *h* are lowered five times as much. But for a similar reason, since the lever *ih* oscillates upon the knife-edge, *i*, the knife-edge *s* is lowered one-fifth as much as the point *h*, and therefore just as much as *g*. The lever *eg* therefore descends parallel to itself, and therefore also the platform A.

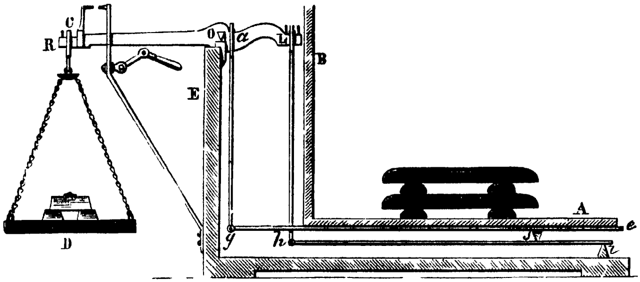


Fig. 39.

Secondly; it follows, moreover, from the proportional division of the levers OL and *ih*, that the pressure at the point of suspension, exercised by the load on the platform, is independent of the place which it occupies on the latter, so that it just acts as if it were applied along the rod *ag*. This may be deduced from the properties of the lever by a simple calculation, which cannot, however, be given here.

Lastly, since the weight is applied at *a*, the longer the arm of the lever OC as compared with O*a*, the smaller need be the weight in the scale D in order to produce equilibrium. In most weighing machines O*a* is the tenth of OC. Hence the weights in the scale D represent one-tenth the weight of the body on the platform.

CHAPTER V.

LAWS OF FALLING BODIES. INCLINED PLANE. THE PENDULUM.

53. **Laws of falling bodies.**—When bodies fall in a vacuum—that is, when they experience no resistance—their fall is subject to the following laws:—

I. *In a vacuum all bodies fall with equal rapidity.*

II. *The space which a falling body traverses is proportional to the square of the time during which it has fallen*; that is, that if the space traversed in a second is 16 feet, in two seconds it will be 64 feet, that is, 4 times as much, and in three seconds 9 times as much, or 144 feet, and so on.

III. *The velocity acquired by a falling body is proportional to the duration of its fall*; that is, that if the velocity at the end of a second is 32 feet, at the end of two seconds it is twice 32, or 64 feet, at the end of three seconds 96 feet, and so forth.

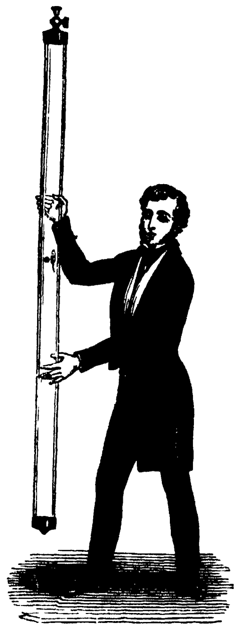


Fig. 40.

To demonstrate the first law by experiment, a glass tube about two yards long (fig. 40) may be taken, having one of its ends completely closed, and a brass stop-cock fixed to the other. After having introduced bodies of different weights and densities (pieces of lead, paper, feather, &c.) into the tube, the air is withdrawn from it by an air-pump, and the stop-cock closed. If the tube be now suddenly reversed, all the bodies will fall equally quickly. On in-

troducing a little air and again inverting the tube the lighter bodies become slightly retarded, and this retardation increases with the quantity of air introduced.

It is, therefore, concluded that terrestrial attraction, which is the cause to which the fall of bodies is due, is equally exerted on all substances, and that the difference in the velocity with which bodies fall is occasioned by the resistance of the air, which is more perceptible the smaller the mass of bodies and the greater the surface they present.

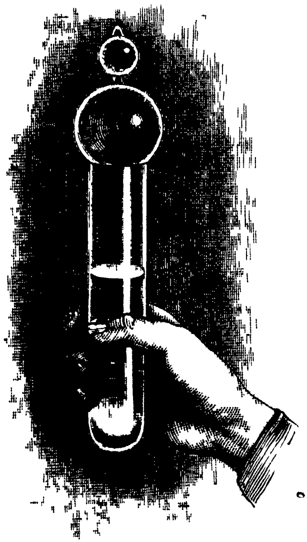


Fig 41.

The resistance opposed by the air to falling bodies is especially remarkable in the case of liquids. The Staubbach in Switzerland is a good illustration; an immense mass of water is seen falling over a high precipice, but before reaching the bottom it is shattered by the air into the finest mist. In a vacuum, however, liquids fall like solids, without separation of their molecules. The *water-hammer* (fig. 41) illustrates this; the instrument consists of a thick glass tube about a foot long, half filled with water, the air having been expelled by ebullition previous to closing one extremity with the blow-pipe. When such a tube is suddenly inverted the water falls in one undivided mass against the other extremity of the tube, and produces a sharp dry sound, resembling that which accompanies the shock of two solid bodies.

The two other laws are verified by the aid of the inclined plane, and of Atwood's machine (fig. 44).

54. **Inclined plane.**—Any plane surface more or less oblique in reference to the horizon is an *inclined plane.* Such is the surface (fig. 42), and such also that of an ordinary desk and of most roads.

When a body rests on a horizontal plane, the action of gravity is entirely counteracted by the resistance of this plane. This,

however, is not the case when it is placed upon an inclined plane; the action of gravity is then decomposed into two forces (26), one perpendicular to the inclined plane, that is, acting along its surface, and the other parallel to the plane. The only effect of the first force is to press the body on the plane without imparting to it any motion; while the second makes the body descend along the plane. This latter, however, is only one component of gravity: it is only a fraction, a third, or a quarter, according to the degree of inclination of the plane. Hence a body will roll down an inclined plane, but more slowly than if it fell vertically; and the velocity is indeed the less the smaller the angle which the plane makes with the horizon.

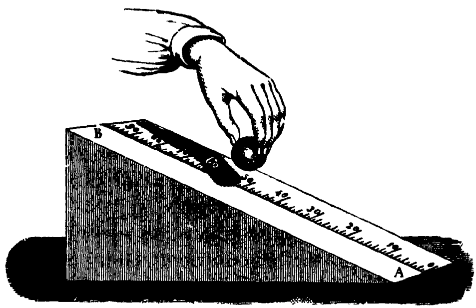


Fig 42

A horse drawing a carriage on a road where there is a rise of one in twenty is really lifting one-twentieth of the load, besides overcoming the friction of the carriage. Hence the importance of making roads as level as possible: it is for this reason that a road up a very steep hill is made to wind or zig-zag all the way, and an intelligent driver, in ascending a steep hill on which is a broad road, usually winds from side to side.

The principle of the inclined plane is made use of in rolling heavy casks into or out of a waggon by means of two strong beams connected by iron ties.

55. **Demonstration of the second law of falling bodies by the inclined plane.**—The above property, which the inclined plane possesses, of slackening the fall of bodies, has been used to demonstrate the second law of their fall (53), that *the space traversed by a falling body is proportional to the square of the time during which it has been falling.*

To make this experiment, an inclined plane is taken, along which is traced a scale graduated in inches; then, taking a well-polished ivory ball, a position is found by trial, at which it just

takes a second to reach the bottom of the inclined plane A, fig. 42. Let us suppose that this is at the eleventh division. The experiment is then repeated by making the ball traverse four times the distance, that is, placing it at the forty-fourth division, and it will then be found to take two seconds in so doing. In like manner it will be found that in passing through nine times the distance, or through ninety-nine divisions, three seconds are required. Hence it is concluded that the spaces traversed increase as the squares of the times.

56. **Atwood's machine.**—In ordinary circumstances the velocity of falling bodies is too rapid to be directly observed. Mr. Atwood invented a machine by which their velocity is slackened, and the laws of motion may be demonstrated. It consists of a wooden pillar about 2½ yards high (fig. 51). On the front of the pillar is a clockwork motion H, regulated in the usual way by a seconds pendulum, P. On the right of the column is a graduated scale which measures the spaces traversed by the falling bodies. Along this scale two sliders move, which can be fixed by a screw in any position ; one of these has a disc, A, and the other a ring, B (fig. 47). At the top of the column is a brass pulley, R, whose axis, instead of resting on pivots, turns on the crossed edges of four other wheels r, r, r', r', called *friction wheels*, since they serve to diminish friction (fig. 43). Two exactly equal weights, K and K′, are attached to the end of a fine silk thread, which passes round the pulley.

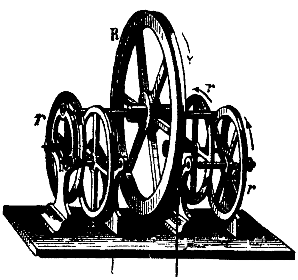


Fig. 43.

At the top of the column is a plate, n, on which is placed the falling body (fig. 44). This plate is fixed to a horizontal axis which carries a small catch, i, supported, when the plate is horizontal, by a lever, ab, movable in the middle. A spring placed behind the dial tends to keep this lever in the position represented in fig. 44, while an eccentric, e, moved by the clockwork, tends to incline towards the right the upper arm of the lever ab. The parts are so arranged that when the needle is at zero of the graduation, the lever ab is moved by the eccentric ; the plate n then lets fall the body which it sustained (fig. 45).

These details being premised, we may add that the slackening

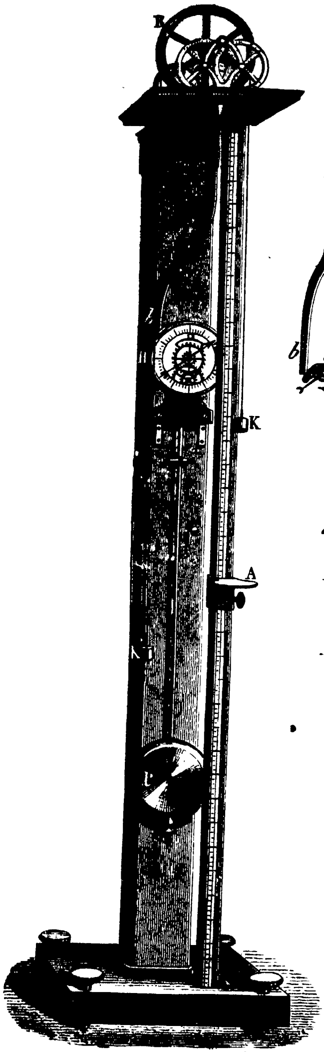


Fig. 51

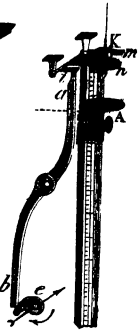


Fig. 44.

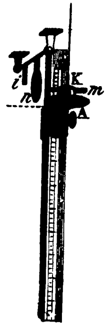


Fig. 45.

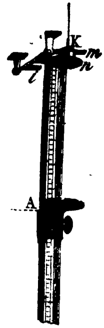


Fig. 46

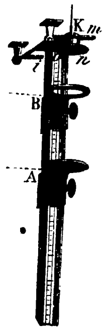


Fig. 47.

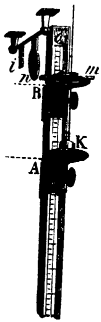


Fig. 48.

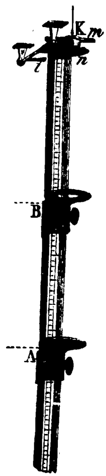


Fig. 49.

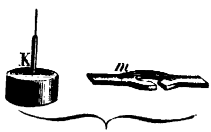


Fig. 50.

which it produces in the fall of a body depends on the mechanical principle that when a moving body meets another at rest, it imparts to this latter a part of its velocity, which is greater the greater the mass of the second body compared with the first. For instance, if a body with the mass 1, strikes against another at rest with the mass 19, the total mass being now 20, the common velocity after the impact is only a twentieth of the original velocity of the first.

First experiment.—To demonstrate the second law, that *the spaces traversed are proportional to the squares of the times*, a weight K is placed upon the ledge *n* (fig. 44), and it is loaded with an over-weight, which consists of a brass disc, *m* (fig. 50), open at the side so as to let pass a rod fixed to the weight K. Then below the ledge *n* the slider A is placed at such a distance that K*m* requires a second to traverse the space *n*A, which is easily obtained after a few trials. If the mass *m* fell alone, it would traverse about 16 feet in a second; but, from the principle stated above, it can only fall by imparting motion to the masses K and K′ which it carries with it; and hence its fall is the more diminished, the smaller the mass *m*, as compared with the sum of the masses K and K′.

The experiment being prepared as indicated in fig. 44, the pendulum is made to oscillate; the clockwork then begins to move, and when the needle arrives at zero, the plate *n* drops (fig. 45), the weights K and *m* fall too, and the space *n*A is traversed in a second by a uniformly accelerated motion. The experiment is recommenced, the slider A being placed at four times its original distance; that is, that if the distance A*n* were 8 inches (fig. 47) it is now 32 inches (fig. 47). But here when the plate *n* drops, it is found that the weight K*m* requires exactly two seconds to traverse the space A*n*. Increasing the space traversed to 72 inches, the time required for the purpose is found to be three seconds. That is, that when the times are twice or thrice as great, the spaces traversed are four or nine times as great.

Second experiment.—To prove the law that *the velocities are proportional to the times*, the experiment is arranged as shown in figs. 47, 48, and 49; that is, the weights K and *m* being arranged as in the first experiment on the ledge *n*, the sliding ring B is placed at a distance of 8 inches below this, and the disc A at 16 inches below. When the ledge *n* has dropped, the weights K and *m* still require a second to fall from *n* to B. But then the over-weight *m* being arrested by the ring B (fig. 48), the weight K only falls in virtue of

its acquired velocity. The motion which was uniformly accelerated from *o* to B (17) is kept uniform from B to A; for the weight *m* was the cause of the acceleration, and this having ceased to act, the acceleration ceases. It is then found that the space *o*B, equal to 8, having been traversed in one second, the space BA, equal to 16, is also traversed in a second. That is, 16 represents the velocity of the uniform motion, which, starting from the point B, has succeeded to the uniformly accelerated motion.

The experiment is finally recommenced by placing the sliding ring B at the distance 32 (fig. 49), and the sliding disc below B, also at the distance 32. The space *o*B being then four times as great as in fig 47, the weights K and *m* require, in accordance with the second law, twice the time. But the mass *m* being again arrested by the slider B, it is found that the weight K falls alone and uniformly from B to A in one second. The number 32 from B to A represents then the velocity acquired, starting from the point B after two seconds of fall. In the first part of the experiment it was ascertained that the velocity acquired after one second was 16; hence, in double the time, the velocity acquired is double. It may be shown, in like manner, that after three times the time, the velocity is trebled, and so on; thus proving the third law.

57. **Pendulum.**—This is the name given to any heavy mass suspended by a thread to a fixed point, or to any metal rod movable about a horizontal axis. The ball, *m*, suspended by the thread *cm*, which is fixed at the top at *c* (fig. 52), is a pendulum.

So long as the thread is vertical, which is the case when the centre of gravity of the ball is exactly below the point of suspension, *c*, the pendulum remains at rest, for the action of gravity is balanced by the resistance at this point. This is no longer the case when the pendulum is removed from its vertical position; when it is placed, for instance, in the direction *cn* (fig. 53). The ball being raised, gravity tends to make it fall; it returns from *n* to *m*, and reaches the latter point with exactly the velocity it would have acquired by falling vertically through the height, *om*. The ball, accordingly, does not stop at *m*, but, in virtue of its inertia, and of its acquired velocity, it continues to move in the direction *mp*; as the ball rises, however, gravity, which had acted from *n* to *m* as an accelerating force, now exerts a retarding action, for it acts in a direction contrary to that of the motion; the motion, accordingly, becomes slower, and the ball stops at a distance, *mp*, which would be exactly equal to *mn*, were it not for the resistance of the air, and

also the rigidity of the thread, *cm*, which, as it is, offers a certain resistance to being bent about the point *c*, in passing from the position *cn* to *cp* and *vice versâ*.

This being premised, the moment the ball stops at *p*, gravity, acting so as to make it fall again, brings it from *p* to *m*, when, owing to its inherent velocity, it rises in effect as far as *n*, and so on; a backward and a forward motion is thus produced from *n* towards *p*, and from *p* towards *n*, which may last several hours.

This motion is described as an *oscillating motion*. The path of the ball from *n* to *p*, or from *p* to *n*, is known as a *semi-oscillation*,

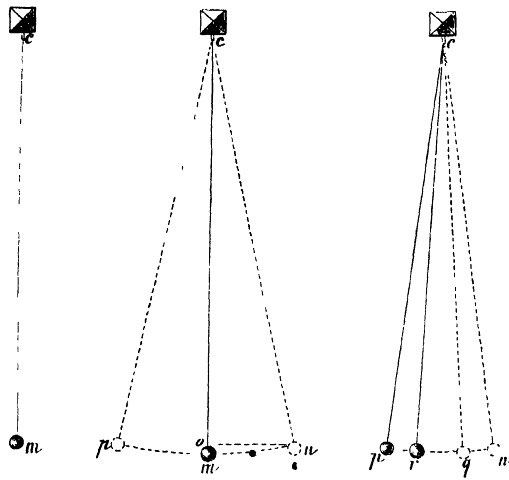


Fig. 52. Fig. 53. Fig. 54.

a *complete oscillation* being the motion from *n* to *p*, *and* from *p* to *n*. In France the former is known as a *single* oscillation, and the backward and forward motion as a *double* oscillation.

The extent or *amplitude* of the oscillation is the distance between the extreme positions, *cn* and *cp*, and is measured by the arc, *pn*.

58. **Simple and compound pendulum.**—A distinction is made in physics between the *simple* and the *compound* pendulum. A *simple* pendulum would be that formed by a *single* material point, suspended by a thread *without* weight. Such a pendulum has merely a theoretical existence; and it has only been assumed in

order to arrive at the laws of the oscillations of the pendulum which we shall presently describe.

A *compound* or *physical pendulum* may be defined to be any body which can oscillate about a point or an axis. The pendulum described above (fig. 52) is of this kind. The form may be greatly varied, but the most ordinary one is a glass or steel or wooden rod (fig. 56) fixed at the top of a thin flexible steel plate, or to a knife-edge like that of the balance (fig. 36). At the bottom of the rod is a heavy lens-shaped mass of metal, usually of brass, and known as the *bob*. The lenticular is preferred to the spherical form, for, for the same mass, it presents less resistance to the air during each oscillation.

59. **Laws of the pendulum. Galileo.**—Whatever be the form of the pendulum, its oscillations always fall under the following laws. The first of these, that one and the same pendulum makes its oscillations in equal times, was discovered by Galileo, the celebrated physicist and astronomer, at the end of the sixteenth century. It is related that he was led to this discovery, while still young, by observing the regular motion of a lamp suspended to the vault of the cathedral at Pisa. This property of the pendulum has received the name of *isochronism*, from two Greek words which mean equal times, and such oscillations are said to be *isochronous*.

First law; or, law of isochronism.—*The oscillations of one and the same pendulum are isochronous, that is, are effected in equal times.* This law is only perfectly exact when the oscillations are of small amplitude, four or five degrees at most; for a greater amplitude the oscillation is longer.

Second law; or, law of lengths.—With pendulums of different lengths *the durations of the oscillations are proportional to the square roots of the lengths of the pendulums*: that is to say, that if the lengths of the pendulums are as 1, 4, 9, 16, the times of oscillations will be as 1, 2, 3, 4; these being the square roots of the former set of numbers.

A pendulum 9·76 inches in length makes an oscillation in half a second; while one 156 inches long requires two seconds to make a single oscillation.

Third law.—If the length of the pendulum remains the same, but the substances are different, the *duration of the oscillations is independent of the substance of which the pendulums are formed*; that is, that whether of wood, or of ivory, or of any kind of metal, they all oscillate in the same length of time.

Fourth law.—*The duration of the oscillations of a given pendu-*

lum is inversely as the square root of the force of gravity in the place in which the observation is made.

60. **Demonstration of the laws of the pendulum.**—In order to demonstrate the laws of the simple pendulum we are compelled to employ a compound one, the construction of which differs as little as possible from that of the simple one (58). For this purpose a small sphere of a very dense substance, such as lead or platinum, is suspended from a fixed point by means of a very fine thread. A pendulum thus formed oscillates almost like a simple pendulum, the length of which is equal to the distance of the centre of the sphere from the point of suspension.

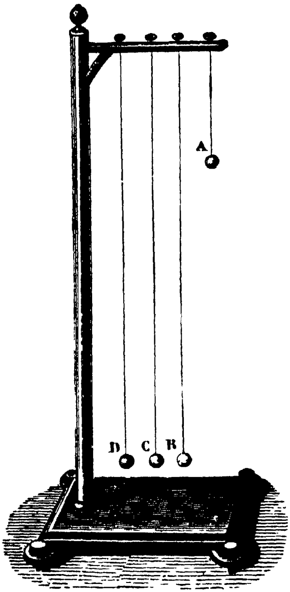


Fig. 55.

In order to verify the isochronism of small oscillations, it is merely necessary to count the number of oscillations made in equal times, as the amplitudes of these oscillations diminish from *pn* to *rq* (fig. 54) say from three degrees to a fraction of a degree; this number is found to be constant.

That the times of vibration are proportional to the square roots of the lengths is verified by causing pendulums whose lengths are as the numbers 1, 4, 9, . . . to oscillate simultaneously. (AB, fig. 55). The corresponding numbers of oscillations in a given time are then found to be proportional to the fractions 1, $\frac{1}{2}$, $\frac{1}{3}$, etc. . . . which shows that the times of oscillation increase as the numbers 1, 2, 3, . . . etc.

By taking several pendulums of exactly equal lengths B, C, D (fig. 55), but with spheres of different substances, lead, copper, ivory, it is found that, neglecting the resistance of the air, these pendulums oscillate in equal times, thereby showing that the accelerating effect of gravity on all bodies is the same at the same place.

61. **Measurement of the force of gravity.**—The relation which the fourth law of the pendulum establishes between the number of oscillations in a given time, and the force of gravity, is

used to determine the magnitude of this force at different places on the globe. By counting the number of oscillations which one and the same pendulum makes in a given time, a minute for example, in proceeding from the equator towards the poles, it has been found that this number continually increases, proving, therefore, that the force of gravity increases from the equator towards the poles.

By means of the pendulum the velocity has been calculated which a body acquires in falling, in a second of time, in a vacuum; that is to say, when it experiences no resistance from the air. At London this is 32·19 feet.

Since the velocity which a force imparts to a movable body in a given time is greater in proportion as the force is greater, the force of gravity in different places is measured by the velocity which it imparts to a body falling freely in a vacuum; while at London, for instance, its intensity is 32·19, at the Equator it is 32·09, and at Spitzbergen 32·25 feet.

62. **Application of the pendulum to clocks.**—The regulation of the motion of clocks is effected by means of pendulums, that of watches by balance-springs. Pendulums were first applied to this purpose by Huyghens in 1658, and in the same year Hooke applied a spiral spring to the balance of a watch. The manner of employing the pendulum is shown in fig. 56. The pendulum rod passing between the prongs of a fork, *a*, communicates its motion to a rod, *b*, which oscillates on a horizontal axis, *o*. To this axis is fixed a piece, *mn*, called an *escapement* or *crutch*, terminated by two projections or *pallets*, which work alternately with the teeth of the *escapement wheel*, R. This wheel being acted on by the weight tends to move continuously, let us say in the direction indicated by the arrowhead. Now, if the pendulum is at rest, the wheel is held at rest by the pallet, *m*, and with it the whole of the clockwork and the weight. If, however, the pendulum moves and takes the position shown by the dotted line, the pallet *m* is raised, the wheel *escapes*

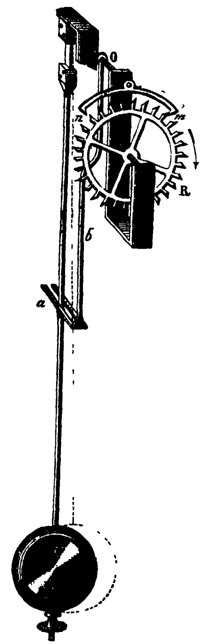


Fig. 56.

from the confinement in which it was held by the pallet, the weight descends, and causes the wheel to turn until its motion is arrested by the other pallet *n*; which, in consequence of the motion of the pendulum, will be brought into contact with another tooth of the escapement wheel. In this manner the descent of the weight is alternately permitted and arrested—or, in a word, *regulated*—by the pendulum. By means of a proper train of wheelwork the motion of the escapement is communicated to the hands of a clock; and consequently their motion, too, is regulated by the pendulum.

Hence, to regulate a clock when it goes too slow or too fast, the length of the pendulum must be altered. If the clock goes too slow, it is because the pendulum oscillates too slowly, and it must therefore be shortened; if, on the contrary, it goes too fast, it must be lengthened. This shortening or lengthening is usually effected at the top of the pendulum by varying the length of the oscillating portion of the plate to which it is suspended. Clocks are provided with a simple arrangement for this purpose, which, however, is not represented in the figure.

A pendulum which makes one oscillation in a second is called a *seconds pendulum*. Its length is not the same in different parts of the earth; it is somewhat less at the equator than at the poles. In London it amounts, in round numbers, to 39·14 inches, and in New York to 39·10 inches, and at the Equator to 39·02 inches.

Seeing that heat expands bodies, the length of the pendulum will be greater in summer and less in winter. Hence a clock which has been once regulated for the mean annual temperature will lose in summer and will gain in winter. How this effect of temperature is counteracted by a self-acting arrangement will be seen in the chapter on Heat.

63. **Determination of the figure of the earth.**—Richter, a French astronomer, found in 1671, in a journey from Paris to Cayenne, which is near the Equator, that a clock which kept correct time in Paris went more slowly in Cayenne. It lost as much as $2\frac{1}{2}$ minutes in a day, an amount greater than could have been due to the lengthening of the pendulum owing to the action of heat; and in order to regulate the clock it was necessary to shorten the pendulum by about the $\frac{1}{10}$ of an inch. The converse phenomenon was also observed, that the pendulum which had been regulated to be at seconds at Cayenne went

too fast at Paris, and had to be lengthened to a corresponding extent.

The true cause of this phenomenon was first pointed out by Newton, who ascribed it to the fact that the earth was not perfectly spherical; for if it were, then, on every part of the earth's surface, one and the same pendulum would be at the same distance from the centre of gravity and would oscillate everywhere at the same rate. The fact that in some places it oscillates more slowly than in others is a proof that in the former the pendulum is less acted on by gravity than in the latter—that is, it is a greater distance from the centre of gravity.

Subsequent very accurate measurements have established the fact that the force of gravity does diminish from the equator to the poles: that is, the surface of the earth at the poles is nearer the centre of gravity than at the equator, or that the earth is somewhat flattened at the poles.

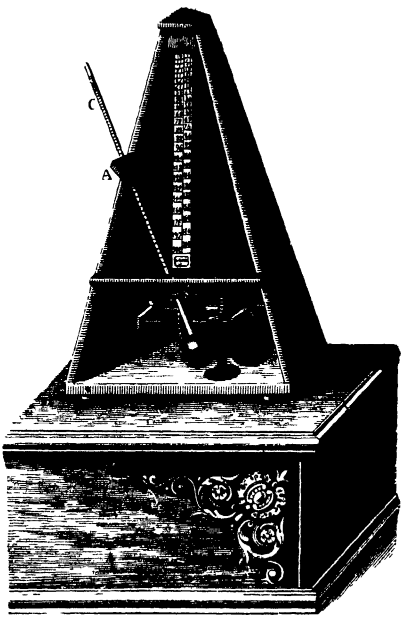


Fig. 57.

64. **Metronome.**—This is another application of the isochronism of the oscillations of the pendulum, and is used to mark the time in practising music. As the time varies in different compositions it is important to be able to vary the duration of the oscillations, which is effected as follows. The bob of the pendulum, B (fig. 57), is of lead and it oscillates about an axis, *o*; the rod which is prolonged above this axis is provided with a weight, A, which slides on this rod and can be fixed in any position. This weight obviously acts in opposition to the oscillations of the bob, B, for when this tends to oscillate, for

instance, from right to left, the weight tends to move the rod in the opposite direction, and this resistance which it affords to the motion is greater the longer the arm of the lever, A*o*, on which it acts. Hence the higher the weight, A, is raised, the slower are the oscillations. At the base of the instrument there is a clockwork motion, which works an escapement with such force that, at each oscillation of the pendulum, a tooth strikes strongly against a pallet fixed to the axis, *o*, thus producing a regular beat which gives the time. In front of the box which contains the mechanism is a scale with numbers, indicating the height at which the weight must be placed to obtain a given number of oscillations in a minute. In the figure this weight is at the number 92, which indicates that the pendulum makes 92 oscillations in a minute.

CHAPTER VI.

MOLECULAR ATTRACTION.

65. **Cohesion and chemical affinity.**—After having described, under the name of *universal gravitation*, the attraction which exists between the stars and planetary bodies; and under that of *gravity*, the attraction which the earth exerts upon all bodies in making them fall towards it, we have to investigate the attractions which hold together the ultimate particles or molecules of a body. These are—cohesion, chemical affinity, and adhesion.

Cohesion is the force which unites two molecules of the same nature; for example, two molecules of water, or two molecules of iron. Cohesion is strongly exerted in solids, less strongly in liquids, and scarcely at all in gases. Its density decreases as the temperature increases, because then the repulsive force due to heat increases. Hence it is that when solid bodies are heated, they first expand, then liquefy, and are ultimately converted into the gaseous state, provided that heat produces in them no chemical change.

Cohesion varies not only with the nature of bodies, but also with the arrangement of their molecules: for example, the difference between tempered and untempered steel is due to a difference in the molecular arrangement produced by tempering. Many of the properties of bodies, such as tenacity, hardness, and ductility, are due to the modifications which this force undergoes.

Soldering is due to cohesion; the surface of the metals must be quite clean, which is effected by removing the layer of oxide with which they are usually coated by acid or by borax. The solder when it solidifies only adheres to clean metal surfaces.

In large masses of liquids, the force of gravity preponderates over that of cohesion. Hence liquids acted upon by the former force have no special shape; they take that of the vessel in which they are contained. But in smaller masses cohesion gets the upper hand, and liquids present then the spheroidal form. This is seen in raindrops and in the drops of dew on the leaves of plants; it is also seen when a liquid is placed on a solid which it does not

moisten ; as, for example, mercury upon wood. The same result may also be obtained with water, by sprinkling upon the surface of the wood some light powder such as lycopodium or lampblack, and then dropping some water on it. Molten lead, falling from a sieve at the top of a shot tower, acquires the form of perfect spherical drops, which it retains on cooling.

A very interesting experiment illustrating cohesion, consists in introducing some coloured olive oil by means of a pipette into a mixture of alcohol and water in such proportions as to have exactly the same specific gravity (105) as the oil (fig. 58) ; the latter does not mix with the surrounding liquid, but remains suspended in it as a sphere, which, if the experiment is carefully performed, has a larger diameter than that of the neck of the vessel.

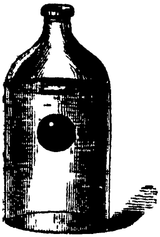


Fig 58.

In dropping various liquids from bottles it is seen that the size of the drops is not the same, that of water is greater than that of alcohol, and it is greatest in those in which cohesion is greatest, and on this fact is based a method of measuring the force of cohesion in different liquids.

Chemical affinity, or *chemical attraction*, is the force which is exerted between molecules not of the same kind. Thus, in water, which is composed of oxygen and hydrogen, it is affinity which unites these elements, but it is cohesion which binds together two molecules of water. In compound bodies cohesion and affinity operate simultaneously, while in elementary bodies cohesion has alone to be considered.

To chemical affinity are due all the phenomena of combustion ; when carbon burns, it is affinity which causes this body to combine with the oxygen of the air to form the gas known as carbonic acid. Affinity determines the combination of the elements, so that with a small number of them are formed the immense number of organic and mineral substances which serve for our daily uses.

The causes which tend to weaken cohesion are most favourable to affinity ; for instance, the action of affinity between substances is facilitated by their division, and still more by converting them to a liquid or gaseous state. It is most powerfully exerted by a body in its *nascent* state : that is, the state in which the body exists at the moment it is disengaged from a compound ; the body is then free, and ready to obey the feeblest affinity. An increase of temperature

modifies affinity differently under different circumstances. In some cases, by diminishing cohesion, and increasing the distance between the molecules, heat promotes combination. Sulphur and oxygen, which at the ordinary temperature are without action on each other, combine to form sulphurous acid when the temperature is raised. In other cases heat tends to decompose compounds; thus many metallic oxides, as for example those of silver and mercury, are decomposed, by the action of heat, into gas and metal.

66. **Adhesion.**—*Adhesion* is the name given to the attraction manifested by two bodies when their *surfaces* are placed in contact. Between adhesion and cohesion there is no real difference; the former term should perhaps be exclusively applied to the case in which the bodies are different.

If two leaden bullets are cut with a penknife so as to form two equal and brightly polished surfaces, and the two faces are turned against each other until they are in the closest contact, they adhere so strongly as to require a force of more than 3 or 4 ounces to separate them. The same experiment may be made with two pieces of perfectly plane brightly polished plate glass, *gg*, fixed in wooden frames, *a b*, *c d*, fig. 59; they are slid over each other with a certain pressure, and then adhere so firmly as not only to hold up the lower glass, but a considerable weight in addition. In some cases the adhesion is so powerful that they cannot be separated without breaking. As the experiment succeeds in a vacuum it cannot be due to atmospheric pressure, but must be attributed to a reciprocal action between the two surfaces. Adhesion between two surfaces is the more complete the longer they have been in contact, and the greater the pressure between them, and the greater the extent of surface; it is also better the more polished the surface, and the freer they are from a layer of air or of metallic oxide.

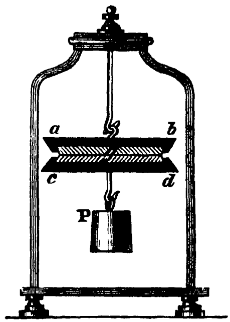


Fig. 59.

To adhesion is due the resistance experienced in raising a plank placed on water; and to the same force is ascribed the difficulty met with in walking through thick mud. If we dip a glass rod into water, on withdrawing it a drop will be found to collect at the bottom, and remain suspended there. As the weight of the drop

tends to detach it, there must necessarily be some force superior to this weight which maintains it there; this force is the force of adhesion. Adhesion is particularly strong when a liquid is brought in contact with a solid, and then solidifies by cooling or evaporation. On this depends the operations of gluing, cementing, and soldering. When two pieces of glass are joined by cement, when the operation has been carefully performed, it often happens that the pieces of glass are torn asunder rather than the cement. The collection of dust on the ceiling and walls of a room; writing with chalk, or with a lead pencil, are also due to adhesion.

The force of adhesion operates also between solids and gases. If a metal plate be immersed in water, bublbes will be found to appear on the surface. As air cannot penetrate into the pores of the plate, the bubbles could not rise from air which had been expelled, but must be due to a layer of air which covered the plate and *moistened* it like a liquid.

Many illustrations may be given of the existence of this layer of condensed gas. If we trace a figure with the finger on an ordinary glass plate and then breathe on the glass the figure becomes visible. Here the original surface layer had been removed, and then the greater condensation of aqueous vapour on the parts from which it was removed brings out the figure.

If the plate be polished, so as to remove this layer and an ordinary coin be placed on it, on afterwards removing the coin and breathing on the glass an impression of the coin is seen. Here the layer of gas originally on the surface of the coin diffuses on to the glass plate, which thereby becomes altered. Conversely if a coin be polished, and laid on an ordinary glass plate, it will partially remove the layer of gas from the parts in contact, so that on breathing on the plate the image is visible.

CAPILLARITY. ABSORPTION.

67. **Capillary phenomena.**—When solid bodies are placed in contact with liquids, molecular attraction gives rise to a class of phenomena called *capillary phenomena*, because they are best seen in tubes so narrow that their diameters are comparable with that of a hair. These phenomena are treated of in physics under the head of *capillarity* or *capillary attraction*: the latter expression is also applied to the force which produces the phenomena.

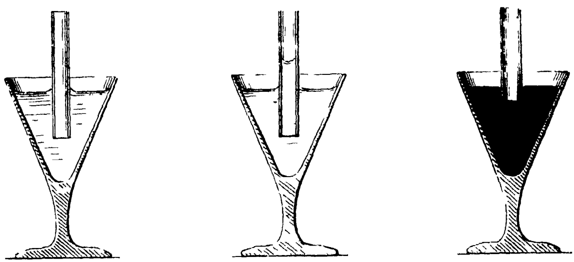
The phenomena of capillarity are very various, but may all be

referred to the mutual attraction of the liquid molecules for each other, and to the attraction between these molecules and solid bodies. The following are some of these phenomena :—

i. When a glass rod is placed in a liquid which wets it, water for instance, the liquid, as if not subject to the laws of gravity, is raised upwards against the sides of the solid, and its surface, instead of being horizontal, becomes slightly concave (fig. 60).

ii. If, instead of a solid rod, a hollow tube be immersed in water (fig. 61), not merely is the liquid raised around the tube, but it rises in the inside to a height which is greater the narrower the tube : and at the same time the surface of the liquid inside the tube assumes a concave form.

iii. If the tube is not moistened by the liquid, as is the case with mercury, the liquid is depressed instead of being raised and



the more so the narrower the tube (fig. 62) ; and the surface which was previously concave now becomes convex. The surface of a liquid exhibits the same concavity or convexity against the sides of a vessel in which it is contained, according as the sides are or are not moistened by the liquid.

68. **Laws of capillarity.**—The elevation and depression of liquids in capillary tubes, the internal diameter of which does not exceed two millimètres, are governed by the following laws :—

I. *When a capillary tube is placed in a liquid, the liquid is raised or depressed according as it does or does not moisten the tube, and the elevation is the greater the smaller the diameter of the tube :* that is, that if we have two tubes, one with a diameter of 1 mm., and the other with a diameter of 2 mm., if the ends are

placed in liquid, it would rise in the former tube to double the height to which it would rise in the latter.

II. *The elevation varies with the nature of the liquid, and increases with the temperature.* Thus, in tubes of the same diameter, 1 mm., the heights to which water, turpentine, and alcohol would rise would be 30, 13, and 12 mm. respectively.

69. **Effects due to capillarity.**—It is from capillarity that sap rises in plants, that oil rises in the wicks of lamps, and melted tallow in the wicks of candles. The interstices which exist between the fibres of the cotton, of which the wicks are formed, act as capillary tubes in which the ascent takes place. In very porous bodies, the pores being in communication with each other form a series of capillary tubes, which produce the same effect. If a lump of sugar be placed in a cup in which a little coffee is left, the liquid is seen to rise rapidly and fill the entire piece ; and it is even to be remarked that the sugar then dissolves more quickly than if it had been directly immersed in the coffee. This is due to the fact that in the latter case the air which fills the pores, not being able to escape so rapidly as if the piece of sugar is only partially immersed, prevents the liquid from penetrating into the mass of the sugar, and thus retards the solution. If oil or ink be dropped on the edge of a book, it penetrates to some distance in the leaves.

In petroleum lamps, the liquid by capillary action rises in the wick to a considerable height above the level in the reservoir ; olive oil, for instance, could not be continuously burnt in such a lamp, for, being more viscous (77), it does not rise in the capillary channels rapidly enough to feed the flame. In oil lamps, as well as in candles, the flame is arranged so as to be just above the reservoir of the liquid which feeds them.

Spiders can often move on the surface of water without sinking. Similarly a fine sewing needle gently placed on water does not sink. This is a capillary phenomenon caused by the fact that the cohesion of a free surface of a liquid is greater than in the interior : the surface is, as it were, covered by a stretched liquid membrane like that of an elastic skin, and this *surface layer* can thus support a slight weight. If the needle be washed in alcohol or potash so as to remove the slight layer of grease, it is wetted by the water and at once sinks. It is as if the surface layer were broken.

70. **Absorption and imbibition.**—The words absorption and imbibition are used almost promiscuously in physics ; they indicate the penetration of a liquid or a gas into a porous body. Absorp-

tion is used both for liquids and gases, while imbibition is restricted to liquids.

Charcoal has a great absorbing power for gases If a piece of recently heated charcoal be passed into a bell jar full of carbonic acid placed over a mercury trough (fig. 63), the volume of gas is seen to diminish rapidly, and it is found that the gas which has disappeared in penetrating the charcoal, represents a volume thirty-five times that of the solid. There are even gases, such as ammonia, of which charcoal can absorb ninety times its own volume.

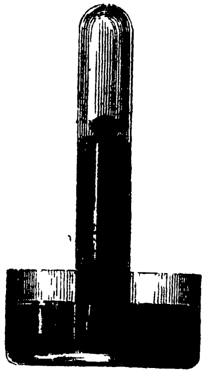


Fig 63

In general those gases which are most easily condensed to the liquid state, are just those which are absorbed to the greatest extent by charcoal; and it is probable that the gases thus absorbed are in the liquid state. To this powerful absorption of charcoal and other porous substances, such as dry earth, for gases, the purifying action of these substances is due.

Absorption takes place in all parts of plants, but more especially in the rootlets and by the leaves. These organs absorb, in the form of water, carbonic acid, and ammonia, the oxygen, hydrogen, carbon, and nitrogen necessary for the growth of the plants.

Absorption also plays an important part both in the nutrition and respiration of animals. Animal tissues can even absorb solid substances. For instance, in those processes of the arts where the workmen have to handle salts of mercury or of lead, these metals are gradually absorbed into the system, and often produce serious and even fatal diseases.

71. **Effects due to imbibition.**—Imbibition has been defined as being the penetration of a liquid into the pores of a solid body. It is a capillary effect, for the pores being in intercommunication act like small tubes; thus it is that water rises in wood, sponge, bibulous paper, sugar, sand, and in all bodies which possess pores of a perceptible size. A clay soil is damp even when it has not rained, owing to its having absorbed aqueous vapour from the air.

Owing to imbibition, tobacco soon dries if kept in a wooden box; while it remains fresh if kept in a metal one, for then its moisture is not absorbed by the metal as it is by the wood.

When animal or vegetable matters absorb water their volume increases. Thus if a tolerably large sheet of dry paper be measured and be then moistened, it will be found to have appreciably expanded by this process. This property is made use of in stretching paper on drawing boards ; the paper is moistened and is then glued or fastened with pins round the edge of the board. In drying, the paper contracts, and is tightly stretched. For the same reason, too, wall papers which have been fastened on cloth along the walls are sometimes liable to be torn.

In bending wood, the side to be bent is heated, and the other side moistened. This latter being lengthened owing to the water it absorbs, while the former is contracted in consequence of the dryness, a curvature ensues on the heated side.

It is often observed that, owing to the changes of volume which they undergo under the influence of moisture and dryness, the furniture of our rooms is heard to crack when the weather changes.

By the absorption of moisture ropes become shorter ; and lengthen when they dry. This may seem opposed to what has been stated about moistened paper, but the explanation is not difficult. Ropes are formed of fibres twisted together, and as these fibres swell owing to the water they absorb, the rope becomes larger, and hence each fibre should make in coiling a longer circuit ; and the rope will become shortened as it is moistened. For this reason, too, new cloths shrink considerably when they are moistened for the first time.

CHAPTER VII.

PROPERTIES SPECIAL TO SOLIDS.

72. **Tenacity.**—Besides the general properties which we have hitherto been considering, and which are met with in solids, liquids, and gases, there are some, special to solids, which require mention, on account of the numerous applications which they present. They are—tenacity, hardness, ductility, and malleability.

Tenacity is the resistance which bodies oppose to being broken, when subjected to a greater or less traction or stretching. The tenacity of any particular body is determined by giving to it the form of a cylindrical or prismatic rod, one end of which is then firmly fixed in a vertical position to a support. To the lower end is fixed a scale pan, in which weights are successively added until the rod breaks. The breaking weight represents the limit of the tenacity of a rod for a given section.

Of all metals iron has the greatest tenacity. A cylindrical iron rod with a section of a square centimètre only breaks with a weight of 13,200 pounds. A rod of boxwood, of the same dimensions, breaks with a weight of 2,640, and one of oak with 1,540 pounds ; a steel wire supports a load represented by a weight of 9,000 times that of its own length ; strands constructed of fine iron wire, the $\frac{1}{25}$th to $\frac{1}{30}$th of an inch in diameter, can support a load of 60 tons for each square inch of section.

Tenacity is directly proportional to the breaking weight, and inversely proportional to the area of a transverse section of the wire.

Tenacity diminishes with the duration of the traction. A small force continuously applied for a long time will often break a wire which would not at once be broken by a larger weight.

Not only does tenacity vary with different substances, but it also varies with the form of the body. Thus, with the same sectional area, a cylinder has greater tenacity than a prism. The quantity of matter being the same, a hollow cylinder has greater tenacity than a solid one.

The shape has also the same influence on the resistance to

crushing as it has on the resistance to traction. A hollow cylinder with the same mass, and the same weight, offers a greater resistance than a solid cylinder. For this reason the bones of animals, the feathers of birds, the stems of corn and other plants, offer greater resistance than if they were solid, the mass remaining the same.

73. **Hardness.**—*Hardness* is the resistance which bodies offer to being scratched or worn by others. It is only a relative property, for a body which is hard in reference to one body may be soft in reference to others. The relative hardness of two bodies is ascertained by trying which of them will scratch the other. Diamond is the hardest of all bodies, for it scratches all, and is not scratched by any. The hardness of a body is expressed by referring it to a *scale of hardness*: that usually adopted is—

1. Talc	5. Apatite	8. Topaz
2. Rock salt	6. Felspar	9. Corundum
3. Calcspar	7. Quartz	10. Diamond
4. Fluorspar		

Thus the hardness of a body which would scratch felspar, but would be scratched by quartz, would be expressed by the number 6·5.

The pure metals are softer than their alloys. Hence, for jewellery and coinage, gold and silver, which are soft metals, are alloyed with copper to increase their hardness.

The hardness of a body has no relation to its resistance to compression. Glass and diamond are much harder than wood, but the latter offers far greater resistance to the blow of a hammer. Hard bodies are often used for polishing powders; for example, emery, pumice and tripoli. Diamond being the hardest of all bodies, can only be ground by means of its own powder.

74. **Ductility.**—*Ductility* is the property owing to which a great number of bodies change their forms by the action of traction or pressure.

Certain bodies, such as clay, wax, &c., are so ductile at ordinary temperatures that they can be drawn out, flattened, modelled between the fingers; others, such as resins and glass, require the aid of heat. Glass is then so ductile that it can be drawn out into fine threads, which are flexible enough to be woven into cloth.

Platinum is the most ductile of all metals. Wollaston obtained a wire of this material 0·00003 of an inch in diameter, by coating a very thin platinum wire with a layer of silver so as to form a cylinder,

which was then drawn out as finely as possible, so that both metals were equally extended. This was then placed in dilute nitric acid, which dissolved the silver, but left the platinum untouched. A mile of this wire would not weigh more than a grain and a quarter.

Several metals, such as gold, silver, copper, are ductile even at ordinary temperatures, but require the use of powerful machines, such as the draw-plate or the rolling-mill.

75. **Malleability.**—Malleability is that modification of ductility which is exhibited when metals are hammered. This property increases greatly with the temperature; every one knows, for instance, that iron is easily forged when hot, and not when cold.

Gold is very malleable even at the ordinary temperature. To make the extremely thin plates of gold known as *gold leaf*, the gold is first pressed, by means of the rolling-mill, into long plates about an inch in breadth, and the $\frac{1}{25}$th of an inch in thickness. These plates are then beaten into small squares by means of a hammer; these are cut and beaten again, and so on. By beating them directly, the operation could not long be continued, for the metal would be torn: hence the plates to be beaten must be placed between plates of a substance which, while thin, affords great resistance. Sheets of vellum and parchment are first used for this purpose, and afterwards *gold-beater's skin.*

Leaves of gold are thus obtained, which are so thin that 300,000 superposed are only an inch thick. Silver and copper may also be worked in the same manner. These leaves are used in the arts for gilding on wood, paper, and other materials.

The following is the usual order of the metals under the draw-plate, the rolling-mill, and the hammer, arranged in reference to their increased ductility.

Draw-plate.	Rolling-mill.	Hammer.
Platinum	Gold	Lead
Silver	Silver	Tin
Iron	Copper	Gold
Copper	Tin	Zinc
Gold	Lead	Silver
Zinc	Zinc	Copper
Tin	Platinum	Platinum
Lead	Iron	Iron

The metals must be pure; if they are alloyed with other metals they are fragile, and have but little ductility.

BOOK II.

ON LIQUIDS.

CHAPTER I.

PRESSURES TRANSMITTED AND EXERTED BY LIQUIDS.

76. **Hydrostatics.**—The science of *hydrostatics*, from two Greek words signifying *equilibrium of water*, treats of the conditions of the equilibrium of liquids, and of the pressures they exert, whether within their own mass, or on the sides of the vessels in which they are contained.

77. **Special characteristics of liquids.**—One essential character of a liquid is the extreme mobility of its molecules, which are displaced by the slightest force. The fluidity of liquids is due to this property; it, however, is not perfect, there is always a sufficient adherence between the molecules to produce a greater or less *viscosity.*

In respect to this property liquids differ greatly; thus ether is extremely mobile, while glycerine has great viscosity.

Another essential property of liquids, and one by which they are distinguished from gases, is their almost entire incompressibility. We have already seen (11) that their compressibility is so small that for a long time they were regarded as being quite incompressible. It was not before 1823 that Oersted, a Swedish physicist, first proved in an exact manner that liquids are compressible. The apparatus he used for this purpose is called the *piezometer* (πιέζω, I compress, μέτρον, measure). By its means it has been found that a pressure of one atmosphere compresses distilled water by about the $\frac{1}{20000}$th part of its volume; mercury by the same pressure only undergoes about one-twelfth as great a diminution; while that of ether is about $2\frac{1}{2}$ times as much.

Liquids are also porous, elastic, and impenetrable, like all other

bodies. The proofs of their porosity have been already given, their elasticity is a necessary consequence of their compressibility. Their impenetrability is manifested whenever a solid is immersed in water. For if a vessel be quite filled with water, and any solid body be placed in it which does not absorb the liquid and in which the solid is insoluble, it will be observed that a volume of water flows over which is exactly equal to that of the solid immersed.

On this property is based a method of determining with accuracy the volume of bodies of irregular shape.

78. **Equality of pressures. Pascal's law.**—Liquids have the following remarkable property, which is often called 'Pascal's law,' for it was first enunciated by that distinguished geometrician.

Pressure exerted anywhere upon a mass of liquid is transmitted undiminished in all directions, and acts with the same force on all equal surfaces and in a direction at right angles to those surfaces.

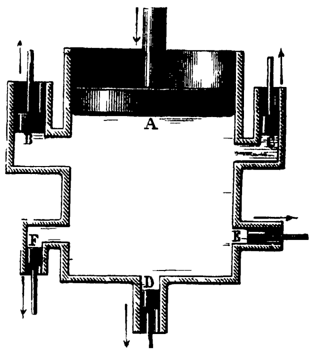


Fig. 64.

To get a clearer idea of the truth of this principle, let us conceive a cylindrical vessel, in the sides of which are placed various cylindrical tubulures, all of the same size, and closed by moveable pistons (fig. 64). The vessel being filled with water, or any other liquid, the moment any pressure is applied to the piston A, all the other pistons are pressed outwards, showing that the pressure is not merely transmitted downwards upon the piston D, but laterally upon the pistons E and F, and upwards upon the pistons B and C. If, instead of pressing on the piston A, the pressure be exerted upon B, the same effects are produced; the piston A is then forced upwards.

In these different cases, not only is the pressure transmitted in all directions, but for the *same surface* it is transmitted with the same force. For instance, if the pressure on the piston A is twenty pounds, and its surface is equal to that of the piston B, the upward pressure on the latter is also twenty pounds; but if the surface of the piston B is only a twentieth that of A, the pressure upon B is only one pound. This is the principle of *the equality of pressure.*

79. **Consequence and verification of Pascal's principle.**—It follows from what has been said that *the pressure transmitted by a liquid is proportional to the extent of surface* ; this is, indeed, only another enunciation of Pascal's principle.

To verify this, two cylinders are taken of unequal dimensions, joined by a tube (fig. 65). These cylinders contain water, and are provided with pistons which move in them with gentle friction. Now, if the surface of the larger one, P, for instance, is twenty times that of the smaller one, *p*, it will be found that a weight of a pound placed upon *p* will balance a weight of twenty pounds placed upon P ; if these weights are in any other ratio, equilibrium is destroyed.

The principle of the equality of pressures forms the basis of the whole science of hydrostatics, and we shall presently find a very important application of it in the *hydraulic press* (85).

80. **Pressures resulting from the weight of liquids.**—In what has been said, we have considered the pressures transmitted towards the sides of the vessel, when some external force is applied. It is not, however, necessary to exert an external pressure on the surface of a liquid in order to produce internal pressures in its mass, and on the sides of the vessel. The mere weight of the liquid itself is sufficient to produce pressures, which vary with the depth and with the density of the liquid.

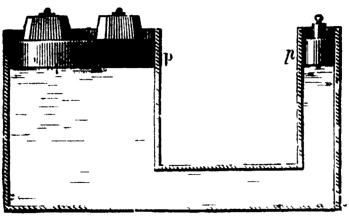


Fig. 65.

For suppose any vessel filled with liquid ; if we conceive the liquid divided into horizontal layers of equal thickness, it is clear that the second layer supports a pressure equal to the weight of the first ; that the third supports the weight of the first and second, and so on ; so that the pressure increases with the number of layers, which is expressed by saying that *gravity produces in liquids pressures proportional to the depth.*

It is obvious, moreover, that *these pressures are proportional to the densities of the liquids* ; that is, that, for the same depth, a liquid which has two or three times the density of another will exert twice or thrice as much pressure.

It follows from the principle of the equality of pressure in all

directions that the pressure produced by gravity in liquids is exerted not merely in the direction of this force, but *horizontally*, and also *upwards*, as will now be demonstrated.

81. **Lateral pressures. Hydraulic tourniquet.**—The existence of pressures which liquids exert upon the sides of the vessel in which they are contained, or lateral pressures, may be demonstrated by means of the *hydraulic tourniquet* or *Barker's mill* (fig. 66). This consists essentially of a long glass tube, C, with a funnel, D, at the top. The bottom of the tube fits into a hollow brass box, which rests on a pivot; in the sides of the box are fitted four brass tubes, arranged crosswise, and all bent in the same direction at the ends.

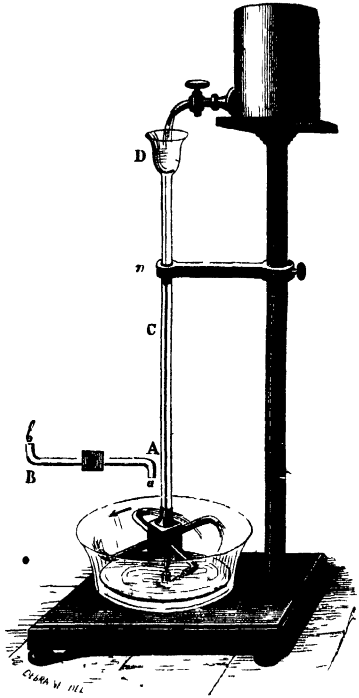


Fig. 66

Water descending the long tube emerges by the apertures of the bent tubes, which are soon seen to rotate rapidly in the direction indicated by the arrow. This rotation is due to the lateral pressure exerted by the column of water in the long tube. For let us consider one of the bent tubes, *a*A, B*b*, represented in section on the left (fig. 66), and suppose first that the orifices, *a* and *b*, are closed. The column of water which then fills the tube C exerts upon the portions of the opposite sides, A and *a*, equal and contrary pressures which hold each other in equilibrium; this is also the case at B and *b*, and thus no rotation can be produced in either direction. But if the orifices *a* and *b* are open, as is the case when the apparatus is at work, as the water issues by these orifices, the pressures at *a* and *b* no longer exist,

while those transmitted to A and B, continuing to act, produce the rotation.

The action of this lateral pressure may also be illustrated by placing a cylinder (fig. 67), filled with water, on a piece of cork, or on a board which is floated on water. In one side of the vessel is a stopcock, and on removing this the water jets out; the pressure on this side is less than on the opposite one, and accordingly the vessel floats on the water in the direction opposed to that in which the jet is issuing.

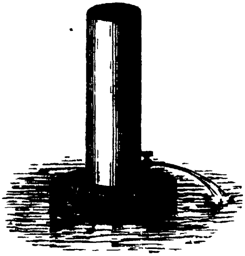


Fig. 67.

Rotating fireworks also act on the same principle as Barker's mill; that is, an unbalanced reaction from the heated gases which issue from openings in them gives them motion in the opposite directions.

The principle of Barker's mill is of extended use in the construction of those hydraulic motors which are known as *turbines*.

It is in consequence of the lateral pressure of water that dykes and banks, which retain rivers or reservoirs or canals, sometimes give way by becoming too weak for the pressure they have to support.

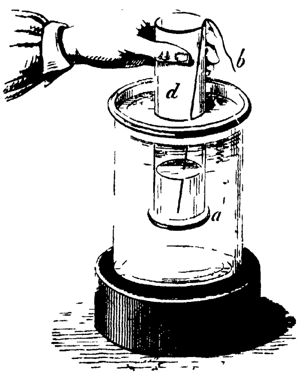


Fig. 68.

82. **Vertical upward pressure.**—The pressure which the upper layers of a liquid exert on the lower layers causes them to exert an equal reaction in an upward direction, a necessary consequence of the principle of transmission of pressure in all directions.

The following experiment (fig. 68) serves to exhibit the upward pressure of liquids. A large open glass tube, one end of which is ground, is fitted with a ground glass disc, *a*, or, still better, with a thin card or piece of mica, the weight of which may be neglected. To the disc is fitted a string, *b*, by which it can be held against the bottom of the tube. The whole is then immersed in water, and the disc does not fall, although no longer held by the string; it is conse-

quently kept in its position by the upward pressure of the water. If water be now slowly poured into the tube, the disc will only sink when the height of the water inside the tube is equal to the height outside. It follows thence that the upward pressure on the disc is equal to the pressure of a column of water, the base of which is the internal section of the tube *a*, and the height the distance from the disc to the outer surface of the liquid. Hence *the upward pressure of liquids at any point is governed by the same laws as the downward pressure.*

This upward pressure is termed the *buoyancy* of liquids ; it is perceived when the hand is plunged into water, and still more distinctly if it is immersed in mercury, which, being of greater density, produces greater pressure. It is owing to this that, if a leak be produced in the bottom of a ship, water rushes in with great force.

83. **Pressure is independent of the shape of the vessel.**—The pressure exerted by a liquid, in virtue of its weight, on any

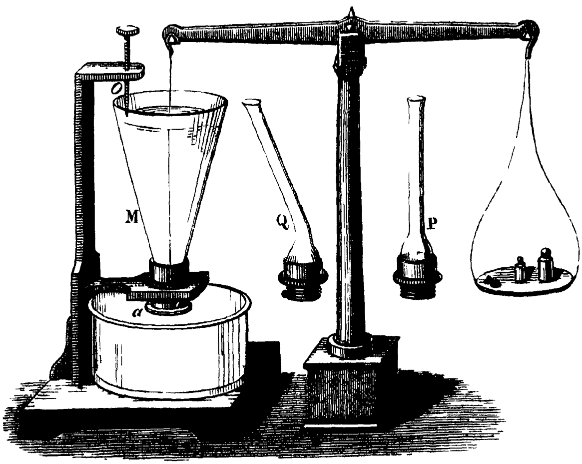


Fig. 69.

portion of the liquid, or on the sides of the vessel in which it is contained, depends on the depth of the liquid and on its density but *is independent of the shape of the vessel and of the quantity of the liquid.*

This principle, which follows from the law of the equality of

pressure, may be experimentally demonstrated by many forms of apparatus. The following is one frequently used, and is due to Masson. It consists of a large conical vessel, M, screwed to a brass tubulure, *c*, fixed to a wooden support (fig. 69). This tubulure is closed by a disc, *a*, which does not adhere to it, but is simply applied against the edge, and is kept there by a string attached to one end of an ordinary balance, to the other end of which is a scale-pan. Weights are placed in the latter, so as just to counterbalance the pressure of the water on the disc, when the vessel M is almost full; water is then gradually added until the disc just begins to give way and allows some to escape. A rod, *o*, is then lowered until its point just grazes the surface of the liquid. If the vessel M be unscrewed and replaced by the cylindrical tube, P, the capacity of which is far less, on gradually pouring water in, the moment the level of the liquid just touches the point of the rod, *o*, the disc, *a*, begins to allow some water to escape. The same result ensues if for the straight tube, P, the inclined one, Q, be substituted. In these three cases, therefore, provided the height of the liquid is the same, the pressure on the disc, *a*, is the same, whatever be the shape and capacity of the vessels.

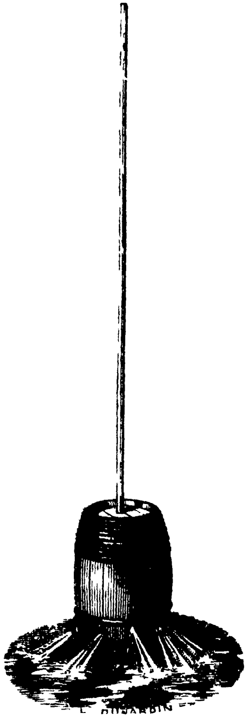


Fig. 70.

Moreover, the weight which has to be put on the scale-pan to establish equilibrium shows that *the pressure exerted by the liquid is equal to the weight of a column of water the base of which is the internal section of the tubulure, c, and the height the vertical distance from the disc to the surface of the liquid.*

This principle is sometimes called the *hydrostatical paradox*, for at first sight it seems quite impossible.

84. **Pascal's experiment.**—Pascal made the following experiment, which proves what great pressures may be produced by even

small quantities of liquid when contained in vessels of great height. He fixed firmly in a stout cask, as represented in fig. 70, a very narrow tube about 30 feet in height, and then filled the cask and the tube with water. The effect of this was to burst the cask; for there was a pressure on the bottom of the cask, equal to the weight of a column of water whose base was the bottom itself, and whose height was equal to that of the water in the tube (83).

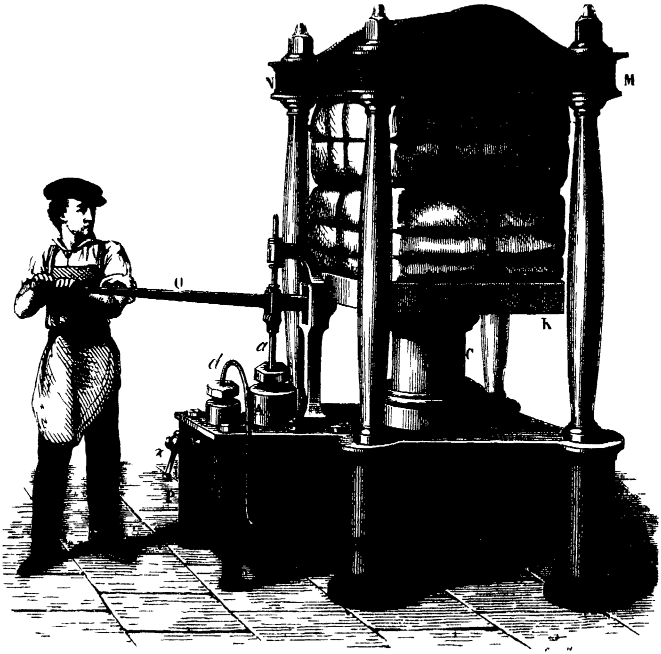


Fig. 71

85. **Hydraulic press.**—The law of the equality of pressure has received a most important application in the *hydraulic press*, a machine by which enormous pressures may be produced. Its principle is due to Pascal, but it was first constructed by Bramah in 1796.

Fig. 71 represents an elevation, and fig. 72 a section of the instrument; it consists of two iron cylinders or barrels, A and B,

of unequal diameters. In the barrel, A, which is of very small diameter, is a cylindrical rod, *a*, which acts as piston and can be moved up and down by the lever, O. In the cylinder, B, the internal diameter of which is 12 to 15 times that of the barrel, A, is a long cylindrical iron ram, C, which also forms a piston, and works water-tight in the barrel B. On the top of the ram, C, is a thick iron slab, K, which rises and falls with it. Four wrought-iron columns support a second plate, MN, which is fixed. The objects to be pressed are placed between K and MN.

When the piston is raised by means of the lever, a vacuum is produced in the barrel A, and a valve, S, at the bottom opens and

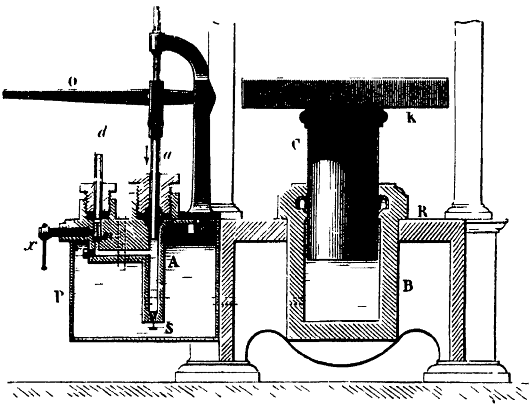


Fig. 72.

allows water to pass from a reservoir, P, into the barrel. When *a* redescends, the valve, S, closes; but another valve, *m*, placed at the bottom of the tube *d*, opens; the water is thus forced by this tube into the large cylinder, B. At the next stroke of the piston, *a*, a fresh quantity of water is drawn from the reservoir, P, and forced into the barrel B, and so forth.

In consequence of the principle of the equality of pressure, the downward pressure exerted by the small piston, *a*, is transmitted upwards upon the piston C. The pressure which can be obtained depends on the relation between the size of the piston C and that of the piston *a*. If the former has a transverse section fifty or a hundred times as large as the latter, the upward pressure on the

large piston will be fifty or a hundred times that exerted upon the small one. By means of the lever, O, an additional advantage is obtained. If the distance from the fulcrum to the point where the power is applied is five times the distance from the fulcrum to the piston, *a*, the pressure on *a* will be five times the power (34). Thus if a man acts on O with a force of sixty pounds, the force transmitted by the piston *a* will be 300 pounds, and the force which tends to raise the piston C will be 30,000 pounds, supposing the section of C is a hundred times that of *a*.

The hydraulic press is used in nearly all cases in which great pressures are required. It is applied in compressing cloth, hay, cotton, and gunpowder ; in extracting the juice of beetroot, in expressing oil from seeds, and in pressing apples in making cider ; in the extraction of stearine and in flattening paper and cloth ; it also serves to test the strength of cannon, of steam boilers, and of chain cables, and to bend iron plates. The parts composing the tubular bridge which spans the Menai Straits were raised by means of a hydraulic press. The cylinder of this machine, the largest which had ever been constructed, was nine feet long and twenty-two inches in internal diameter ; it was capable of raising a weight of two thousand tons.

The principle of the hydraulic press is also applied to the working of heavy cranes, the opening of dock gates, and to *hydraulic lifts*, which are of such extensive use in large warehouses, hotels, and the like.

CHAPTER II.

LQUILIBRIUM OF LIQUIDS.

86. **Conditions of the equilibrium of liquids.**—We have seen that the conditions of the equilibrium of a solid are that its centre of gravity be supported by a fixed point; all the other parts of the body then retain the same state of equilibrium, in consequence of cohesion, which unites the particles to each other, and to the centre of gravity. This is by no means the case with liquids; owing to the greater mobility of their molecules, and the facility with which they obey the force of gravity, they would flow away and spread out in a horizontal position, if they were not retained by some obstacle. Hence a liquid cannot be at rest in any vessel, unless it satisfies the following conditions :—

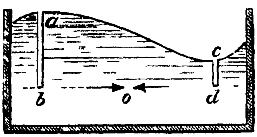


Fig 73.

I. *The free surface of the liquid must be horizontal, that is, perpendicular everywhere to the direction of gravity.*

II. *Each molecule of the mass of the liquid must be subject in every direction to equal and contrary pressures.*

The second condition is self-evident; for if, in two opposite directions, the pressures exerted on any given molecule were not equal and contrary, the molecule would be moved in the direction of the greater pressure, and there would be no equilibrium. Thus the second condition follows from the principle of the equality of pressures, and from the reaction which all pressure causes on the mass of liquids.

To account for the first condition relative to the free surface of the liquid, let us observe that in a liquid whose surface is horizontal, all the molecules supporting each other, the action of gravity is destroyed, and the liquid is at rest. But if the surface is not horizontal, if some parts are higher than others (fig. 73), the highest part, *ab*, exerts upon any horizontal layer, *bd*, a greater pressure than the part *cd*, and therefore, since any given

molecule *o*, of the horizontal layer is exposed to a greater pressure in the direction *bo* than in the direction *do*, equilibrium is impossible.

In saying that for a mass of liquid to be at rest its surface must be horizontal, we must remark that that presupposes the liquid to be only acted upon by gravity, which is usually the case; if it is under the action of other forces, as is the case with the capillary phenomena (67), where it is attracted by the sides of the vessel, its surface is then inclined so as to be perpendicular to the resultant of all the forces which act upon it.

87. **Level of liquids.**—A liquid is said to be *level* when all the points of its surface are in the same horizontal plane. This, how-

ever, only applies to surfaces of small extent. For, as the direction of the vertical constantly changes from one place to another on the surface of the globe, the directions of the horizontal surfaces change too; that is to say, a plane which is horizontal at one part of the earth's surface is not parallel to a horizontal plane at a small distance; they form a very small angle with each other. Hence a liquid surface of some extent in a state of equilibrium, being necessarily horizontal in each of its parts, does not form one single perfectly plane surface, but a series of plane surfaces inclined to each other; which of course produces a curved surface. This curvature cannot,

however, be perceived on surfaces of small extent, as in water contained in a vessel; for the surface of such a liquid is so level that it reflects the rays of light like the most perfectly polished plane mirror. The curvature is, however, easily observed on large surfaces like those of the sea. For if this surface were perfectly level, a ship in sailing away from the shore would only cease to be visible in consequence of increasing distance, and the less apparent parts, the masts and the cordage, would disappear first. This, however, is not the case; the hull first sinks below the horizon, then the lower parts of the masts, and ultimately the top, as seen in fig. 74, thus proving the curvature of the surface of the sea.

88. **True and apparent level.**—When we consider a great surface of water—the Mediterranean Sea, for instance—its surface is said to be level when all points of the surface are equidistant from the centre of the earth. This is the *true level*; while that level which is defined as having all the points of its surface in the same horizontal plane, is the *apparent level*, the level for the eye. The true level only coincides with the apparent level when the liquid surfaces are very small. If the earth did not rotate about its own axis, the surface of all seas would form a true level; but owing to the centrifugal force which results from its daily motion (30), the surface is heaped up at the equator, and the level is higher than at the poles.

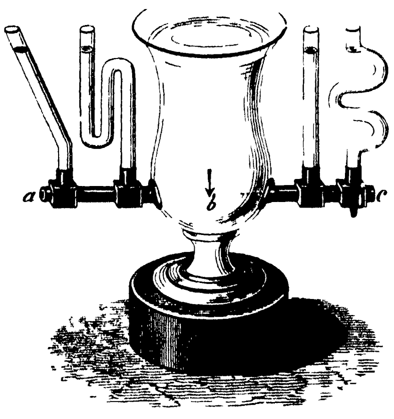


Fig. 75.

89. **Equilibrium of the same liquid in several communicating vessels.**—Not merely do liquids tend to become level when they are placed in the same vessel, but also when they are placed in vessels which communicate with each other. Whatever the shape and the dimensions of these vessels, equilibrium will exist *when the surfaces of the liquids in all the vessels are in the same horizontal plane.*

This principle may be demonstrated by means of the apparatus represented in fig. 75. It consists of a series of vessels of different shapes and capacities connected together by a common horizontal tubulure. When water or any other liquid is poured into the vessel, the level is seen to rise at the same time, and to stop at exactly the same height in each. Equilibrium is then established. For we have seen that the pressures exerted by a liquid do not depend upon its quantity, but upon its height (83); when this is the same, the pressure is necessarily everywhere equal for all the vessels above the tube of communication *abc*, and therefore, as the liquid has no more tendency to flow from *b* towards *a* than from *b* to *c*, equilibrium continues.

90. **Equilibrium of different liquids in communicating vessels.**—In what has been said, the communicating vessels all contained the same liquid. It may, however, happen that the

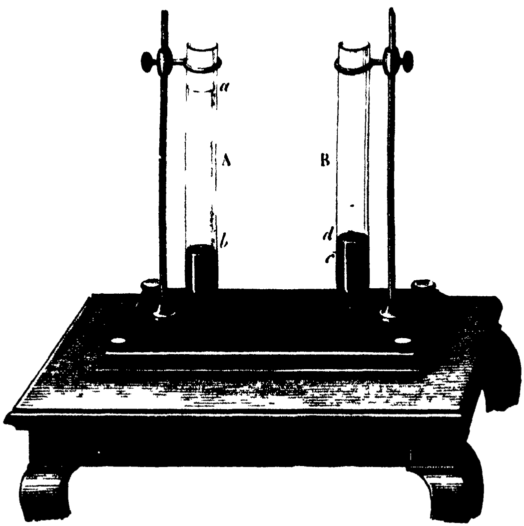


Fig. 76

vessels contain liquids of different densities, which do not mix. The level is then no longer the same; the lighter liquids are higher, and equilibrium is only possible *when the heights of the liquid columns in communication are inversely as their densities;*

that is, if one of the liquids is twice or thrice as dense as another, its height will be half or one-third as much.

This principle is demonstrated experimentally by means of the apparatus represented in fig. 76. It consists of two glass tubes connected at the bottom by a narrow tube. The tubes are supported by two vertical columns, and on each of them is a scale graduated on the glass itself. If then mercury is poured into one of the tubes, it quickly assumes the same level in each. On now pouring water into the tube A, the level of the mercury is seen to sink in this tube owing to the pressure of the water, and it rises in the other tube. Then, when equilibrium is established, the mercury in B is higher than in the tube A by a quantity, *cd*. It is clear, then, that the pressure of the column of mercury, *cd*, counterbalances the pressure of the column of water *ab*. If now the heights of *ab* and *cd* be measured by means of the graduated scales on the two tubes, it will be found that the height *cd* is 13·6 as small as that of *ab*; which demonstrates the above principle, for we shall presently see that mercury is 13·6 times as heavy as water.

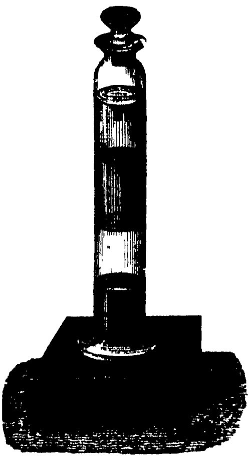


Fig. 77.

91. **Equilibrium of superposed liquids.**—In order that there should be equilibrium when several heterogeneous liquids which do not mix are superposed in the same vessel, each of them must satisfy the conditions necessary for a single liquid; and further, *there will be a stable equilibrium only when the liquids are arranged in the order of their decreasing densities, from the bottom upwards.*

The last condition is experimentally demonstrated by means of the *phial of four elements* (fig. 77). It consists of a long narrow bottle containing mercury, water saturated with carbonate of potass, alcohol coloured red, and petroleum. When the phial is shaken the liquids mix, but when it is allowed to rest they separate; the mercury sinks to the bottom, then comes the water, then the alcohol, and then the petroleum. This is the order of the decreasing densities of the bodies. The water is saturated with carbonate of potass to prevent its mixing with the alcohol.

This separation of the liquids is due to the same cause as that which enables solid bodies to float on the surface of a liquid of greater density than their own. In like manner fresh water, at the mouths of rivers, floats for a long time on the denser salt water of the sea; and for the same reason cream, which is lighter than milk, rises to the surface.

APPLICATIONS OF THE PRINCIPLE OF THE EQUILIBRIUM OF LIQUIDS.

92. **Water level.**—In a great number of operations, such as the construction of canals, railways, roads, etc., it is frequently necessary to determine the difference in level of two more or less distant

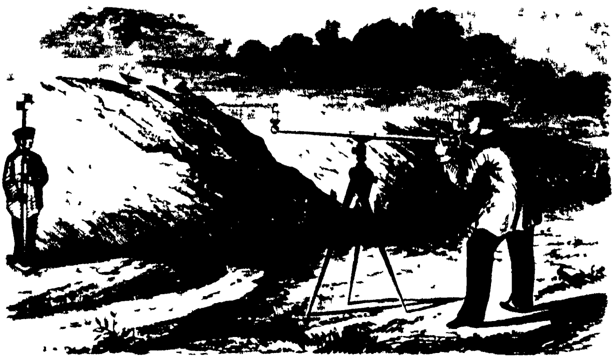


Fig. 78

places. The simplest apparatus for this purpose is the *water level*, which is an application of the conditions of equilibrium in communicating vessels. It consists of a metal tube bent at both ends, in which are fitted glass tubes (fig. 78). It is placed on a tripod, and water poured in the tube until it rises in both limbs. When the liquid is at rest, the level of the water in both tubes is the same —that is, they are both in the same horizontal plane.

This instrument is used in levelling, or ascertaining how much one point is higher than another. If, for example, it is desired to find the difference between the heights of two places, a *levelling-staff* is fixed on the distant place. This staff consists of a rule formed of two sliding pieces of wood, one of which supports a piece of tin plate, in the centre of which there is a

mark. This staff being held vertically, an observer looks at i through the level along the surfaces in the two tubes, and directs the holder to raise or lower the slide until the mark is in the line of the level in the two tubes. The assistant then reads off on the graduated rod the height of the mark above the ground. If this height exceeds that of the level, the height of the latter is subtracted from that of the former, and the difference gives the difference in the heights of the two places.

93. **Spirit level.**—The *spirit level* is both more delicate and more accurate than the water level. It consists of a glass tube (fig. 79), very slightly curved; it is filled with spirit with the exception of a bubble of air, which tends to occupy the highest part. The tube is placed in a brass case, which is so arranged that, when it is in a perfectly horizontal position, the bubble of air is exactly between the two points marked in the case. But if the plane on

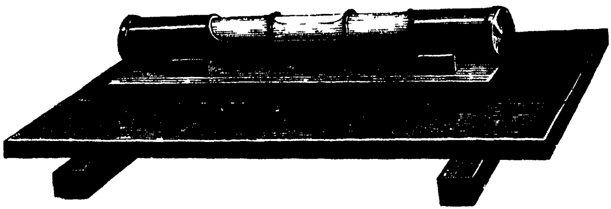


Fig. 79.

which the instrument rests is ever so little inclined, the air bubble tends to move towards the higher part. This, therefore, furnishes a ready means of ascertaining whether any article—a table, a stand, or a bookshelf—is quite horizontal.

To take levels with this apparatus in surveying, it is fixed on a telescope, which can consequently be placed in a horizontal position.

94. **Jets of water.**—The jets which ornament our gardens and public places depend on the tendency of liquids always to become level. For the water which jets out always comes from a reservoir placed in a higher position than that where the jet is; and its jetting is a consequence of its tendency to form a level. Fig. 80 gives an idea of this phenomenon. On the height on the left of the figure is a reservoir containing water, from the bottom of which passes a tube which terminates in the centre of the basin. The water then

jets out, forced by the pressure of a column of water, the height of which is equal to the difference in level between the reservoir and the basin.

Theory proves that in such a case the water always tends to rise to the level of the reservoir from which it is supplied. It never attains this height, for the jet experiences three kinds of resistances: 1st, the friction of the water in the conduit pipe; 2nd, the resistance of the air; and 3rd, the hindrance offered by the particles falling from the top of the jet, upon those ascending.

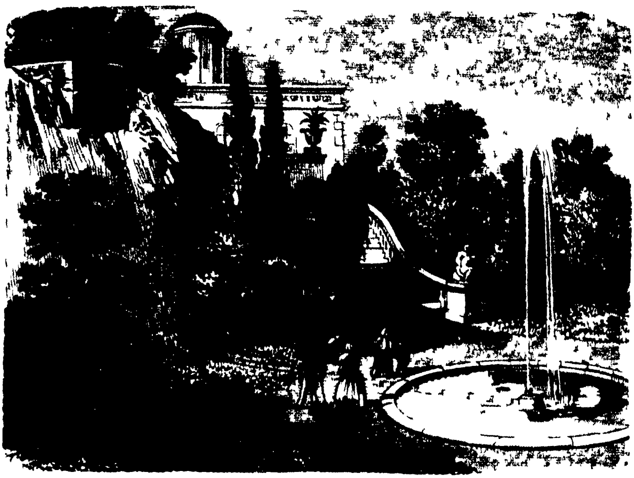


Fig 80

95. **Streams, springs, wells.** – The formation of springs upon the surface of the earth, and in its interior, is also due to the tendency of water to seek its level. For gravity causes water to flow from higher to lower places. Hence it is that the rain which falls upon the earth, and the water arising from the melting of snow, pass down to the valleys, where they form brooks, streams, and rivers, which flow along their beds as along an inclined plane, until they emerge into the seas. A very small fall can give rise to a current. Thus the mean height of the Seine at Paris is not more that 35 yards above the level of the sea. The extent of its course between these two points is about 224 miles, which scarcely amounts to a fall of the $\frac{1}{312}$th part of an inch in a yard; and water requires

several days to traverse this distance. The average fall of the Mississippi is 1 in 900, that of the Rhine between Mannheim and Mainz 1 in 7,400.

The rain which falls does not all flow upon the surface ; part of it penetrates into the earth, and gives rise to small subterranean watercourses which are called *springs*. It is in order to procure water from these that *wells* are sunk.

96. **Artesian wells.**—When the spring which feeds a well comes from a place much higher than that where the well is sunk, it may happen that water tends to rise higher than the ground. This is the case in what are called *Artesian wells*. These wells derive their name from the province of Artois, where it has long been customary to dig them, and whence their use in other parts of

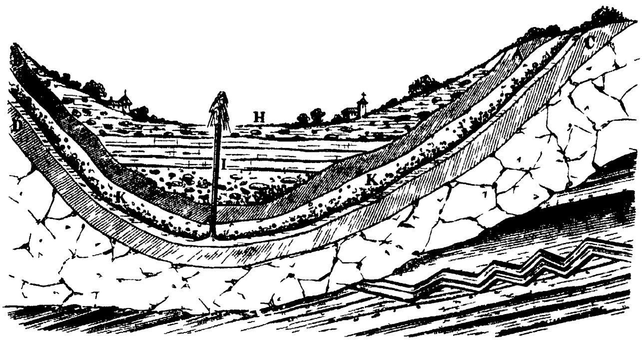


Fig 81

France and Europe was derived. It seems, however, that at a very remote period wells of the same kind were dug in China and Egypt.

To understand the theory of these wells, it must be premised that the strata composing the earth's crust are of two kinds : the one *permeable* to water, such as sand, gravel, chalk, &c. ; the other *impermeable*, such as clay. Let us suppose, then, a basin of greater or less extent, in which the two impermeable layers AB, CD (fig. 81), imclose between them a permeable layer KK. The rain-water falling on the part of this layer which comes to the surface, which is called the *outcrop*, will filter through it, and, following the natural fall of the ground, will collect in the hollow of the basin, whence it cannot escape, owing to the impermeable

strata above and below it. If now a vertical shaft, I, be sunk down to the water-bearing stratum, the water striving to regain its level will spout out to a height which depends on the difference between the levels of the outcrop and of the point at which the boring is made.

The waters which feed Artesian wells often come from a distance of sixty or seventy miles. The depth varies in different places. The well at Grenelle is 1,800 feet deep; it gives 656 gallons of water in a minute, and is one of the deepest and most abundant which have been made. The temperature of the water is 27° C. It follows from the law of the increase of temperature with the increasing depth below the surface of the ground (303), that, if this well were 210 feet deeper, the water would have all the year round a temperature of 32° C., which is the ordinary temperature of warm baths.

CHAPTER III.

PRESSURES SUPPORTED BY BODIES IMMERSED IN LIQUIDS. SPECIFIC GRAVITIES. AREOMETERS.

97. **Pressure supported by a body immersed in a liquid.**—When a solid is immersed in a liquid, it is obvious that the pressures which the sides of the vessel support are also exerted against the surface of the body immersed, since liquids transmit pressure in all directions (78). But it is readily seen that the pressures which the immersed body supports do not neutralise themselves, but have a resultant, the tendency of which is to move the body upwards.

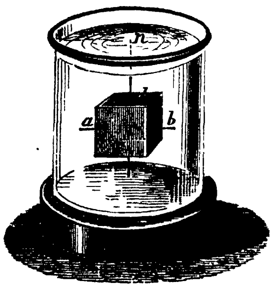


Fig. 82.

Let us imagine a cube immersed in a mass of water (fig. 82), and that four of its edges are vertical. The horizontal pressures upon the two opposite faces, *a* and *b*, are clearly of the same strength, for they are exerted at the same depth (80); and as they are in opposite directions they will balance one another, and the only effect will be to compress the body without displacing it.

But the vertical pressures on the faces *d* and *c* are obviously unequal. The first is pressed downwards by a column of water whose base is the face *d*, and whose height is *dn*; the lower face *c* is pressed upwards by the weight of a column of water whose base is the face itself, and whose height is *cn*. The cube, therefore, is urged upwards by a force equal to the difference between these two pressures, which latter is manifestly equal to the weight of a column of water having the same base and the same height as this cube. By this reasoning, therefore, we arrive at the remarkable principle, that *any body immersed in a liquid is pressed upwards by a pressure equal to the weight of the volume of liquid which it displaces.* We shall see how this principle can be experimentally verified.

98. **Principle of Archimedes. Hydrostatic balance.**—We have thus seen that any body immersed in a liquid is submitted to the action of two forces—gravity which tends to make it sink, and the buoyancy of the liquid which tends to raise it, with a force equal to the weight of the liquid displaced. The body weighs less therefore than in air, and the diminution of its weight is exactly equal to the weight of the displaced liquid. The above principle may be thus enunciated; that *a body immersed in a liquid loses a*

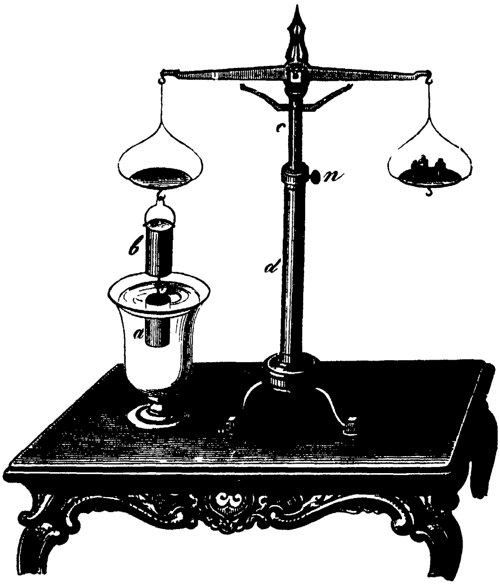


Fig 83.

part of its weight equal to the weight of the displaced liquid. For instance, suppose that a body which weighs 1,000 grains in air displaces a cubic inch of water when immersed in water; it will now only weigh 1,000 − 252 = 748 grains (a cubic inch of water = 252 grains).

This principle, which is remarkable for its numerous applications, is called the 'principle of Archimedes,' after the discoverer. It is shown experimentally by means of the *hydrostatic balance* (fig. 83). This is an ordinary balance, each pan of which is provided with a

hook; the rod, *c*, slides in the hollow cyclinder *d*. The beam is supported on the rod, *c*, which can be fixed in any position by means of a screw, *n*. The beam being raised, a hollow brass cyclinder, *b*, is suspended to one of the pans, and below this a solid cylinder, *a*, whose volume is exactly equal to the capacity of the first cylinder; lastly, an equipoise is placed in the other pan. If now the hollow cylinder, *b*, be filled with water, the equilibrium is disturbed, but if at the same time the beam is lowered so that the solid cylinder *a* becomes immersed in a vessel of water placed beneath it, the equilibrium will be restored. By being immersed in water, the cylinder *a* loses a part of its weight equal to that of the water in the cylinder *b*. Now, as the capacity of the cylinder *a* is exactly the same as that of the cylinder *b*, the principle which has been laid down is proved.

It is stated that Archimedes discovered this principle on the occasion of a problem which had been propounded to him by Hiero, tyrant of Syracuse. This prince, desiring to offer to Jupiter a gold crown, had furnished a goldsmith with ten pounds of gold as the material for this purpose. The crown when finished was found to weigh ten pounds, but Hiero, suspecting that some of the gold had been replaced by silver, demanded from Archimedes a means of detecting the supposed fraud without destroying the crown, owing to the beauty of its workmanship.

Archimedes, pondering over the solution of the problem, was in the bath, when he observed that he could raise his limbs in water more easily than in air. This simple observation was a gleam of light for him; he discovered the above principle, and this led him to a simple means of calculating the quantity of gold and silver in the crown. It is said that Archimedes was so transported with joy at his discovery that he ran home from the bath, crying in the streets, Εὕρηκα (I have found it).

We have all had occasion to make the observation of Archimedes, on observing how much lighter our limbs appear in water, and, on the contrary, how much heavier they seem when lifted out. In like manner, if the body is almost entirely immersed in water, we can walk barefoot on the stones without injuring the feet; but this is not possible when we are out of the water. For in the former case part of the weight of the body is raised by the liquid, while in the latter the whole weight of the body presses the feet against the sharp projections. So, too, a man can raise a stone in water by means of a rope, which he could not do in air.

99. **Equilibrium of immersed and floating bodies.**—When a body is placed in a liquid, three cases are possible: the body may have the same specific gravity as the liquid, in which case it weighs as much as the liquid for an equal volume; or it may be denser, in which case it weighs more; or it is lighter, and in this case it weighs less.

I. If the body immersed is of the same density as the liquid, the weight of the liquid displaced being the same as that of the body, it follows from Archimedes' principle that the buoyancy, which tends to raise it, is exactly equal to the force with which gravity tends to sink it. The two forces are thus in equilibrium, and the body remains in suspension in any position in the liquid.

II. If the body immersed is denser than the liquid, it sinks, for then its weight preponderates over the buoyancy. This is the case when a stone or a mass of metal is thrown into water.

III. Lastly, if the immersed body is lighter than the liquid, the buoyancy prevails, and the body rises until it only displaces a weight of liquid equal to its own. It is then said to *float.* Cork, wax, wood, and all substances lighter than water, float on its surface. Iron floats on mercury.

In order to raise objects sunk in the sea, lighters are moored over them which are so full of water that they only just float, and which are connected with the objects by powerful chains. The water is then pumped out of the lighter, and the buoyancy which is brought into play, by the substitution of air for water, exerts a steadily increasing, and ultimately enormous, pull on the immersed bodies.

The *erratic blocks* of granite and the like which are found far away from the formations to which they belong have been transported by icebergs in which they have been imbedded.

A body which floats on one liquid may sink in another; the body for this purpose must be lighter than the one liquid, but heavier than the other. An egg sinks at once if placed in ordinary water, since it is heavier than an equal volume of water; but it swims if placed in strong brine, which is denser than water. A piece of oak floats on water, but sinks in ether, which is lighter than water. Iron floats on mercury, but sinks at once in water.

Yet a body, though denser than a liquid, may float on its surface. For this purpose it must have such a shape as to displace a volume of liquid the weight of which is greater than its own. Porcelain is much heavier than water, yet a porcelain saucer placed on water

floats on the surface; this arises from its concave shape, owing to which it displaces a weight of water equal to its own, though it is only partially immersed. For the same reason iron hips, even with very thick sides, float freely on water.

100. **Cartesian diver.**—The different effects of suspension, immersion, and floating are reproduced by means of a well-known hydrostatic toy, the *Cartesian diver* (fig. 84). It consists of a glass cylinder nearly full of water, on the top of which a brass cap, A, provided with a piston, is hermetically fitted. In the liquid there is a little porcelain figure, a fish, *o*, for example, attached to a hollow glass ball, *m*, which contains air and water, and floats on the surface. In the lower part of this figure there is a little hole by which water can enter or escape, according as the air in the interior is more or less compressed. The quantity of water in the globe is such that very little more is required to make it sink. If the piston be slightly lowered the air is compressed, and this pressure is transmitted to the water of the vessel and to the air in the bulb. The consequence is, that a small quantity of water penetrates into the bulb, which therefore becomes heavier and sinks. If the pressure is relieved, the air in the bulb expands, expels the excess of water which has entered it, and the apparatus, being now lighter, rises to the surface. The experiment may also be made by replacing the brass cap and piston by a cover of sheet india-rubber, which is tightly tied over the mouth. When this is pressed by the hand, the same effects are produced.

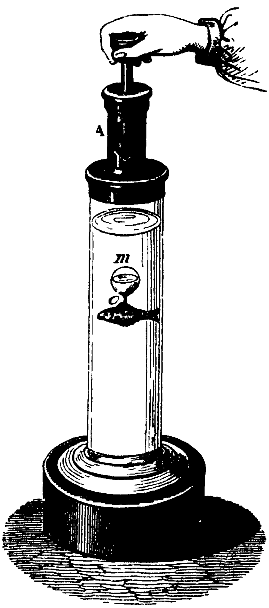


Fig. 84.

101. **Swimming bladder of fishes.**—Most fishes have an air-bladder below the spine, which is called the *swimming bladder*. The fish can compress or dilate this at pleasure by means of a muscular effort, and produce the same effects as those just described—that is, it can either rise or sink in water.

102. **Swimming.**—The human body is lighter, on the whole, than an equal volume of water; it consequently floats on the surface, and still better in sea-water, which is heavier than fresh water. The difficulty in swimming consists, not so much in floating, as in keeping the head above water, so as to breathe freely. In man the head is heavier than the lower parts, and consequently tends to sink, and hence swimming is not natural to him, but is an art which requires to be learned. With quadrupeds, on the contrary, the head, being less heavy than the posterior part of the body, remains above water without any effort, and these animals therefore swim naturally.

If a person who cannot swim, and who falls into the water, retains coolness enough to turn on his back, so that his face is out of water, he can breathe freely, and wait until help arrives. Instead of this, however, he generally attempts to raise his arms out of water, as

Fig 85

if grasping at some fixed support. This is very dangerous, for, as the arms no longer displace a quantity of liquid equal to their own bulk, their weight is not diminished to that extent, but concurs with that of the head in making them sink.

Weight for weight, fat persons swim more easily than lean ones, for they displace more water. For the same reason air bladders, or cork girdles, known as *safety belts*, are fastened to persons who are learning to swim (fig. 85), for then, without any considerable increase of weight, they displace more water, which increases the buoyancy and keeps them up.

Several kinds of birds, such as ducks, geese, and swans, swim easily on water. They owe this property to a thick coating of a light impervious down which covers the lower part of the body, so that they displace, even with a small immersion, a weight equal to their own.

SPECIFIC GRAVITY. HYDROMETERS.

103. **Specific gravity.**—Daily experience shows us that different substances have very unequal weights for one and the same volume. For instance, we all know that gold weighs more than silver, lead than iron, stone than wood. In order to compare equal volumes of various substances as to their weights, the weight of water has been taken as a standard of comparison—as *unity.* For water is everywhere met with, and can always be had pure; this latter condition is necessary, for the weight of a given quantity of water differs with the substances it holds in solution. As, moreover, the weight varies with the temperature, a constant temperature must be adopted. Hence the unit of weight is *distilled* water at a temperature of 4 degrees, for at this point, as we shall afterwards see (232), water has its greatest density.

Thus having agreed to represent by 1 the weight of a certain volume of distilled water at 4 degrees, *the specific gravity* of a body is the weight of *the same volume* of it as compared with that of water, or, what is the same, the number which expresses how much it weighs as compared with water. When we say therefore that the specific gravity of gold is 19, and that of lead 11, we mean that the former metal is 19 times, and the latter 11 times, as heavy as water.

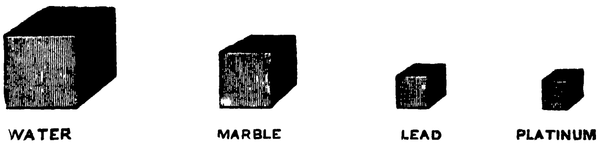


Fig. 86

In order to get a clearer conception of the relative volumes of equal weights of different bodies, let us imagine that the square within which this portion of the text is inclosed represents the side of a cube of air; then the volumes of equal weights of water, marble, lead, and platinum will be represented by the corresponding cubes.

104. **Determination of the specific gravity of solids.**—Three methods are commonly used in determining the specific gravities of solids and liquids. These are—the method of the hydrostatic balance, that of the hydrometer, and that of the specific gravity flask. All three, however, depend on the same principle, that of first ascertaining the weight of a body, and then that of an equal volume of water. We shall first apply these methods to determining the specific gravity of solids, and then to the specific gravity of liquids.

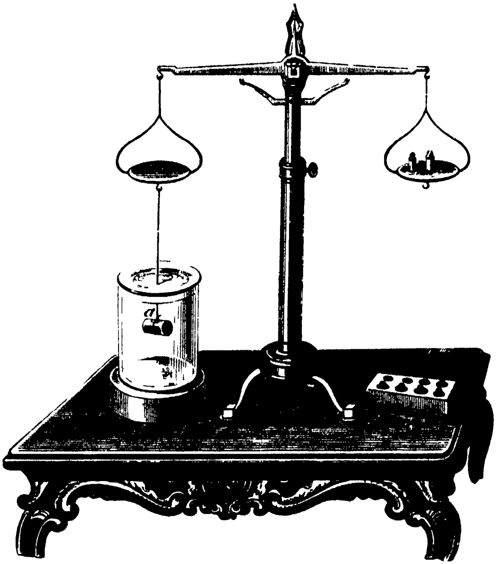


Fig. 87.

i. *Hydrostatic balance.* To obtain the specific gravity of a solid, a piece of iron for instance, by means of the hydrostatic balance (fig. 87), it is first weighed in air by suspending it to the hook of one of the plates. Let us suppose that its weight is 585 grains. It is then weighed while immersed in distilled water, as shown in fig. 85. It will now weigh less; suppose the weight to be 510 grains, this is in accordance with 'Archimedes' principle, for it now loses a weight equal to that of the water which it displaces. Hence,

subtracting 510 from 585, the difference 75 represents the weight of the displaced water, that is, the weight of a volume of water equal to that of the iron: we need now only calculate how often the weight 75, that of the water, is contained in 585, that of the iron, and the quotient 7·8 is the specific gravity of iron; it says that, for equal volumes, this substance weighs 7·8 times as much as water.

Nicholson's hydrometer. This apparatus consists of a hollow metal cylinder (fig. 88), to which is fixed a cone, *d*, loaded with lead. The object of the latter is to lower the centre of gravity so that the cylinder does not upset when in the water. At the top is

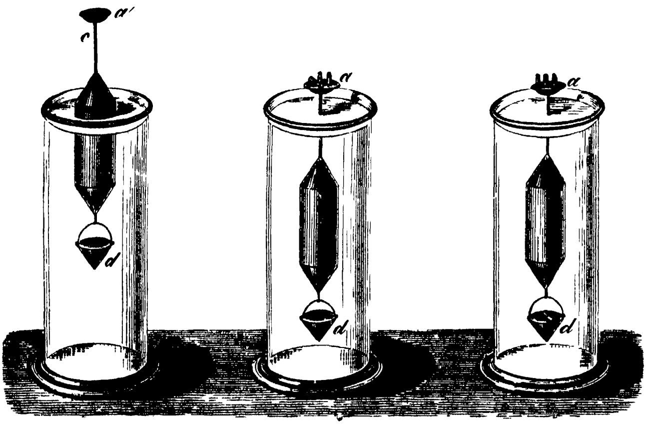


Fig. 88. Fig 89 Fig. 90

a stem, *c*, terminated by a pan, *a*, on which is placed the substance whose specific gravity is to be determined. On the stem a standard point, *c*, is marked.

The apparatus stands partly out of the water, and the first step is to ascertain the weight which must be placed in the pan in order to make the hydrometer sink to the standard point, *c* (fig. 89). Let this weight be 125 grains, and let sulphur be the substance whose specific gravity is to be determined. The weights are then removed from the pan, and replaced by a piece of sulphur which weighs less than 125 grains, and weights added until the hydrometer is again depressed to the standard, *c*. If, for instance, it has been necessary

to add 55 grains, the weight of the sulphur is evidently the difference between 125 and 55 grains, that is, 70 grains.

Having thus determined the weight of the sulphur in air, it is now only necessary to ascertain the weight of an equal volume in water. To do this, the piece of sulphur is placed in the lower pan at *d*, as represented in fig. 90. The whole weight is not changed, nevertheless the hydrometer no longer sinks to the standard point; the sulphur, by immersion, has lost a part of its weight equal to that of the water displaced. Weights are added to the upper pan until the hydrometer sinks again to the standard. This weight, 34·4 grains for example, represents the weight of the volume of water displaced; that is, of the volume of water equal to the volume of the sulphur.

It is only necessary, therefore, to divide 70 grains, the weight in air, by 34·4 grains, and the quotient 2·03 is the specific gravity sought.

Specific gravity flask. In this method, which is advantageously used for the determination of the specific gravity of bodies in a state of powder, a wide-necked bottle is used which can be carefully closed by a ground-glass disc (fig. 91). Having filled it with water, it is closed with the disc, great care being taken that not a bubble of air is left. After being carefully wiped dry, it is placed in the pan of a balance, and by its side is the substance *a*, whose specific gravity is to be determined. The whole is then equipoised by placing weights in the other pan of the balance. The substance, *a*, is then removed, and weights added in its place, until equilibrium is again established. The weight necessary for this purpose gives the weight of the substance in air.

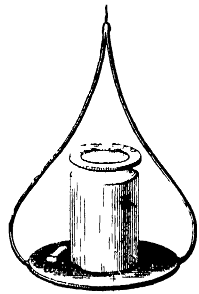


Fig. 91.

To obtain its weight in water it is placed in the flask, the disc adjusted, and the whole again carefully wiped. In order now to equipoise the tare in the second pan, weights must be added on the side of the flask to make up for the water displaced. The weights necessary for this purpose represent then the weight of a volume of water equal to that of the body.

Dividing, then, the weight of the body in air by the weight of an equal volume of water, we have the specific gravity sought.

105. **Specific gravity of liquids.**—These are determined by the same methods as those of solids.

Hydrostatic balance. In determining the specific gravity of a liquid by this means, a body is suspended to one of the pans of the balance, which is neither dissolved by the liquid whose specific gravity is to be determined, nor by water; for instance, a ball of platinum, which is insoluble in all ordinary liquids. This ball is first weighed in air, then in water, and finally in the liquid in question, which we will suppose is alcohol. Let us assume that the ball weighs 510 grains in air, in water 486 grains, and in alcohol 489 grains. The loss of weight in water has thus been 510 less 486, or 24 grains, and in alcohol 510 less 489, or 21 grains; which tells us that if a volume of water equal to that of the ball

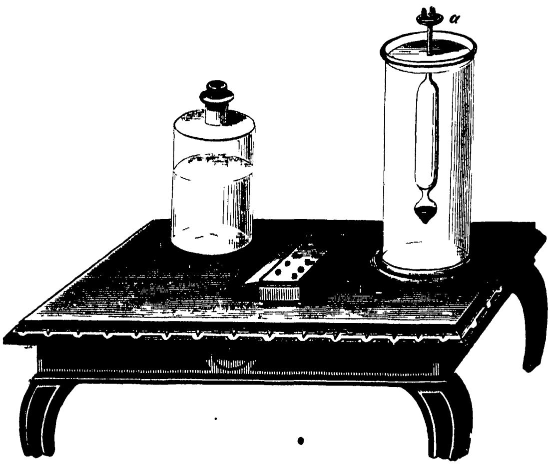


Fig. 92.

weighs 24 grains, the same volume of alcohol weighs 21 grains. Hence to obtain the specific weight of alcohol we must ascertain the number which expresses the ratio 21 to 24, which of course is obtained by division. The quotient thus obtained is 0·866, which represents the specific gravity of alcohol as compared with water.

ii. *Fahrenheit's hydrometer.* This instrument (fig. 92) resembles Nicholson's hydrometer, but it is made of glass, so as to be used in all liquids. At its lower extremity, instead of a pan, it is loaded with a small bulb containing mercury. There is a standard mark on the stem, at the top of which is a pan.

The weight of the instrument is first accurately determined in

air by means of an ordinary balance. Let us suppose that its weight is 618 grains, and that the liquid whose specific gravity is to be determined is olive oil. The hydrometer is placed in water, and the pan loaded with weights, until the liquid is level with the mark on the stem. Suppose it has been necessary to add 93 grains for this purpose; these 93 grains, together with the 618 which the instrument weighs, make 711 grains, which represent the weight of water displaced by the instrument (99). The hydrometer is then removed, wiped dry, and immersed in the olive oil. Let us suppose that now only 31 grains need be added to sink the hydrometer to the mark. These, together with the 618 grains which the instrument weighs, in all 649, represent the weight of the displaced oil. We thus learn that equal volumes of oil and water weigh respectively 649 and 711. Hence we obtain the specific gravity of the latter as compared with the former by dividing 649 by 711. The quotient is 0·91, which teaches us that if a certain volume of water weighs 100 grammes, the same volume of oil weighs 91 grammes.

Fig. 93.

Neither Fahrenheit's nor Nicholson's hydrometers give such accurate results as the specific gravity bottle.

Specific gravity bottle. This consists of a cylindrical reservoir, *b* (fig. 93), to which is fused a narrow tube, *c*, and to this again a wider one, *a*, closed by a stopper. In determining the specific gravity of a liquid, the bottle is first weighed empty, and then, successively, full of water and of the given liquid to the mark *c*. If the weight of the empty bottle be subtracted from the two weights thus obtained, the result represents the weights of equal volumes of water and of the liquid under experiment, from which the specific gravity is obtained by division.

Specific gravities of solids.

Platinum	22·07	Aluminum	2·68
Gold	19·36	Glass	2·48
Lead	11·35	Anthracite	1·80
Silver	10·47	Coal	1·32
Copper	8·87	Amber	1·07
Iron	7·78	Oak	0·84
Zinc	6·86	Yellow pine	0·65
Diamonds	3·53	Common poplar	0·38
Statuary marble	2·83	Cork	0·24

Specific gravities of liquids.

Mercury	13·60	Distilled water at 0° C.	0·99
Bromine	2·96	Claret	0·99
Sulphuric acid . . .	1·84	Olive oil	0·91
Milk	1·03	Oil of turpentine . .	0·87
Sea water . . .	1·02	Absolute alcohol . .	0·80
Distilled water at 4° C.	1·00	Ether	0·72

106. **Use of tables of specific gravities.**—Tables of specific gravity admit of numerous applications. In mineralogy the specific gravity of a mineral is often a highly distinctive character. Jewellers also use them. By means of tables of specific gravities the weight of a body may be calculated when its volume is known, and conversely the volume when its weight is known.

With a view to explaining the last-mentioned use of these tables, it will be well to explain the connection existing between the British *units of length, capacity, and weight.* It will be sufficient for this purpose to define that which exists between the *yard*, *gallon*, and *pound avoirdupois*, since other measures stand to these in well-known relations. The yard, consisting of 36 inches, may be regarded as the primary unit. Although this is essentially an arbitrary standard, it is determined by this—that the simple pendulum which makes one oscillation in a second, at London on the sea level, is 39·1375 inches long (62). The gallon contains 277·274 cubic inches. A gallon of distilled water at the standard temperature weighs 10 lbs. avoirdupois, or 70,000 grains troy ; or, which comes to the same thing, one cubic inch of water weighs 252·5 grains.

On the French system the *metre* is the primary unit, and is so chosen that 10,000,000 metres are the length of a quadrant of the meridian from either pole to the equator. The metre contains 10 decimetres, 100 centimetres, or 1,000 millimetres ; its length equals 1·0936 of a yard. The unit of the measure of capacity is the *litre* or cubic decimetre. The unit of weight is the *gramme*, which is the weight of a cubic centimetre of distilled water at 4° C. The kilogramme contains 1,000 grammes, or is the weight of a decimetre of distilled water, at 4° C. The gramme equals 15·443 grains.

Suppose it is required to calculate the weight of a cubic foot of coal. A cubic foot contains 1,728 cubic inches ; the weight of a cubic foot of water would therefore be 1,728 times 252·5 grains ; this being the weight of one cubic inch of water. The product of this

multiplication divided by 7,000 grains (the number contained in a pound avoirdupois) gives 62·3 pounds as the weight of a cubic foot of water ; and as we learn, from the tables, that coal is 1·32 times as heavy as water, the weight of a cubic foot of coal will be 1·32 times 62·3, or 83·16 pounds.

107. **Hydrometers of variable immersion.**—The hydrometers of Nicholson and Fahrenheit are called *hydrometers of constant immersion but variable weight*, because they are always immersed to the same depth, but carry different weights. There are also *hydrometers of variable immersion but of constant weight*, known under the different names of *acidometer*, *alcoholometer*, *lactometer*, and *saccharometer*.

108. **Beaumé's hydrometer.**—This, which was the first of these instruments, may serve as a type of them. It consists of a glass tube, AB (fig. 94), loaded at its lower end with mercury, and with a bulb blown in the middle. The stem, the external diameter of which is as regular as possible, is hollow, and the scale is marked upon it.

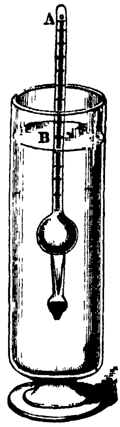


Fig. 94.

The graduation of the instrument differs according as the liquid, for which it is to be used, is heavier or lighter than water. In the first case it is so constructed that it sinks in water nearly to the top of the stem, to a point A, which is marked zero. A solution of fifteen parts by weight of salt in eighty-five parts of water is made, and the instrument immersed in it. It sinks to a certain point on the stem, B, which is marked 15 ; the distance between A and B is divided into 15 equal parts, and the graduation continued to the bottom of the stem. Sometimes the graduation is on a piece of paper in the interior of the stem.

The hydrometer thus graduated only serves for liquids of a greater specific gravity than water, such as acids and saline solutions. For liquids lighter than water a different plan must be adopted. Beaumé took for zero the point to which the apparatus sank in a solution of 10 parts of salt in 90 of water, and for 10° he took the level in distilled water. This distance he divided into 10°, and continued the division to the top of the scale.

The graduation of these hydrometers is entirely arbitrary, and they give neither the exact densities of the liquids ncr the quantities dissolved. But they are very useful in making mixtures or

solutions in given proportions; the results they give being sufficiently near in the majority of cases. For instance, it is found that a well-made syrup marks 35° on Beaumé's hydrometer, from which a manufacturer can readily judge whether a syrup, which is being evaporated, has reached the proper degree of concentration.

109. **Gay-Lussac's alcoholometer.**—The spirits of wine and the brandy in daily use are essentially a mixture of pure alcohol and water. The more alcohol they contain the stronger they are; the more water they contain so much the weaker are they. Hence it is important to have a simple means of exactly determining the quantity of water contained in spirituous liquors. This is effected by means of Gay-Lussac's *alcoholometer*, which has the same shape as Beaumé's, and only differs in the graduation. This is effected as follows:—

Mixtures of absolute alcohol and distilled water are made, containing 5, 10, 20, 30, etc., per cent. of the former. The alcoholometer is so constructed that, when placed in pure distilled water, the bottom of its stem is level with the water, and this point is zero. It is next placed in absolute alcohol, which marks 100°, and then successively in mixtures of different strengths, containing 10, 20, 30, etc. per cent. The divisions thus obtained are not exactly equal, but their difference is not great, and they are subdivided into ten divisions, each of which marks *one* per cent. of absolute alcohol in a liquid. Thus a brandy in which the alcoholometer stood at 48 would contain 48 per cent. of absolute alcohol, and the rest would be water.

All these determinations are made at 15° C., and for that temperature only are the indications correct. For, other things being the same, if the temperature rises, the liquid expands, and the alcoholometer will sink, and the contrary if the temperature falls. To obviate this error, Gay-Lussac constructed a table which for each percentage of alcohol gives the reading of the instrument for each degree of temperature from 0° up to 30°. When the exact analysis of an alcoholic mixture is to be made, the temperature of the liquid is first determined, and then the point to which the alcoholometer sinks in it. The number in the table corresponding to these data indicates the percentage of alcohol. From its giving the percentage of alcohol this is often called the *centesimal alcoholometer*.

Tweddell's hydrometer is in common use in England for liquids denser than water. It is graduated so that the reading or number

of degrees multiplied by 5 and added to 1000 gives the specific gravity referred to water at 1000. Thus 10° Tweddell represents the specific gravity 1050, and 90° represents 1450.

110. **Lactometer.**—The lactometer is a form of hydrometer especially graduated for the purpose of ascertaining the quality of milk (fig. 95). This is accomplished in the following manner. The instrument is immersed in a vessel containing pure milk, and the point to which it sinks is marked zero on a paper strip affixed to the stem. Mixtures are then made of $\frac{9}{10}$ of milk and $\frac{1}{10}$ of water; of $\frac{8}{10}$ and $\frac{2}{10}$, and so on to $\frac{5}{10}$ of milk and $\frac{5}{10}$ of water. The lactometer is successively immersed in these, and sinks to different depths; the point at which it stops in each case is marked by a number on the stem, and thus indicates a milk of a particular strength—that is, one containing a certain quantity of admixed water.

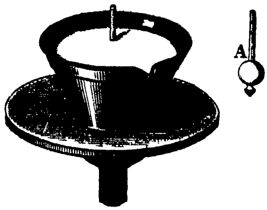


Fig 95.

The lactometer is, however, no infallible test for the adulteration of milk; for the density of natural milk is subject to variation, and an apparent fraud may really be due to a bad natural quality of milk.

BOOK III.

ON GASES.

CHAPTER I.

PROPERTIES OF GASES. ATMOSPHERE. BAROMETERS.

111. **Physical properties of gases.**—Gases, as we have already seen, are bodies whose molecules are in a constant state of repulsion, in virtue of which they possess the most perfect mobility, and are continually tending to occupy a greater space. This property of gases is known by the names *expansiblity*, *tension*, or *elastic force*, from which they are often called *elastic fluids*.

The number of gases with which chemistry makes us acquainted is very considerable ; but only four are elementary : these are oxygen, hydrogen, nitrogen, and chlorine. Some gases are coloured, but most of them are colourless. Some have a disagreeable odour, others are quite inodorous. Some are noxious, acting as poison to men and animals which breathe them ; such are carbonic oxide, which is produced by the combustion of charcoal ; sulphuretted hydrogen, which is given off from drains. Others are inoffensive, such as nitrogen and hydrogen ; yet an animal cannot live in them. They are not deleterious, in the sense of being poisonous ; but they do not support life. The only gas which has this property is oxygen ; an animal deprived of this gas, even for a short time, soon dies.

Gases and liquids have several properties in common, and some in which they seem to differ are in reality only different degrees of the same property. Thus, in both, the particles are capable of moving ; in gases quite freely ; in liquids not quite freely, owing to a certain degree of viscosity. Both are compressible, though in very different degrees : if a liquid and a gas both exist under a pressure of one atmosphere, and then the pressure be doubled, the

water is compressed by about the $\frac{1}{20000}$th part (77), while the gas is compressed by one-half. In density there is great difference; water, which is the type of liquids, is about 770 times as heavy as air, the type of gaseous bodies, while under a pressure of one atmosphere. The property by which gases are distinguished from liquids is their tendency to indefinite expansion.

Matter assumes the solid, liquid, or gaseous form according to the relative strength of the cohesive and repulsive forces exerted between its particles. In liquids these forces balance; in gases repulsion preponderates.

By the aid of pressure and of very low temperatures, the force of cohesion may be so far increased in gases that they are converted into liquids. On the other hand, heat, which increases the force of repulsion, converts liquids, such as water, alcohol, and ether, into the aëriform state in which they obey all the laws of gases. This aëriform state of liquids is known by the name of *vapour*, while gases are bodies which, under the ordinary conditions of temperature and pressure, remain in the aëriform state.

In describing the properties of gases we shall, for obvious reasons, have exclusive reference to atmospheric air as their type.

112. **Atmospheric air.**—Air is the gaseous fluid in which we live. It was regarded by the ancients as one of the four elements. Modern chemistry, however, has shown that it is a mixture of oxygen and nitrogen gases in the proportion of 20·8 volumes of the former to 79·2 volumes of the latter. By weight it consists of 23 parts of oxygen to 77 parts of nitrogen.

The oxygen feeds all the combustions which are produced round about us; and it also supports animal life. If it alone were present, or even if it were present in a larger proportion, combustion would be too brisk, and life too active. The coal of our fireplaces would burn almost instantaneously, and even the iron grates in which it is contained might take fire. Life would be promptly destroyed by so active an agent. The function of the nitrogen is to attenuate the too powerful effects of the oxygen.

Air is inodorous, transparent, and colourless, at any rate in small masses. In larger masses it is blue; thus arises the blue colour of the sky. Without air the celestial vault would appear black; it appears almost so when viewed from the tops of very high mountains, and from balloons; for then the air above is very highly rarefied.

Air, too, in virtue of its elasticity, is the medium for transmitting

sounds; so that, if we were without it, the use of speech and of music would be lost.

113. **Expansibility of gases.**—This property of gases, their tendency to assume continually a greater volume, is exhibited by means of the following experiment. A bladder closed by a stopcock, moistened so as to render it more flexible, and about half full of air, is placed under the receiver of the air-pump (fig. 96), and a partial vacuum is produced, on which the bladder immediately distends. This arises from the fact that the molecules of air repel each other, and press against the sides of the bladder. Under ordinary conditions this internal pressure is counterbalanced by the air in the receiver, which exerts an equal and contrary pressure. But when this pressure is removed, by exhausting the receiver, the internal pressure becomes evident. When air is again admitted into the receiver, the bladder resumes its original form. The same effects would be produced whatever gases were contained in the bladder, thus showing that all are expansible.

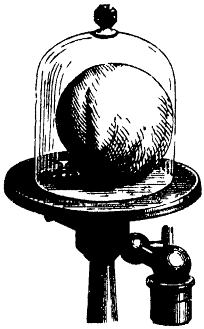


Fig 96

114. **Weight of gases.**—From their extreme fluidity and expansibility, gases seem to be uninfluenced by the force of gravity; they nevertheless possess weight, like solids and liquids. To show this, a glass globe of 3 or 4 quarts capacity is taken (fig. 97), the neck of which is provided with a stopcock, which hermetically closes it, and by which it can be screwed to the plate of the air-pump. The globe is then completely exhausted, and its weight determined by means of a delicate balance. Air is now allowed to enter, and the globe again weighed. The weight in the second case will be found to be greater than before, and, if the capacity of the vessel is known, the increase will obviously be the weight of that volume of air.

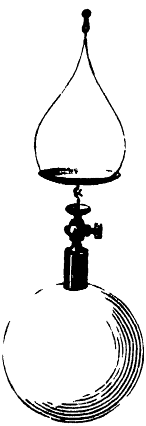


Fig. 97.

By a modification of this method, and with the adoption of certain precautions, the weight of air and of other gases has been determined (234). 100 cubic inches of dry air under the ordinary atmospheric pressure of 30 in. and at the temperature of 16° C.

weigh 31 grains ; the same volume of carbonic acid gas under the same conditions weighs 47·25 grains ; 100 cubic inches of hydrogen, the lightest of all gases, weigh 2·14 grains ; and 100 cubic inches of hydriodic acid gas weigh 146 grains.

The ratio of the density of air at 0° C. and 30 inches pressure to that of water at 0° C. is found to be as 0·001293 : 1. In other words, the latter is about 773 times as heavy as the former.

115. **The atmosphere. Experiments proving its weight.**—The *atmosphere* is the name given to the layer of air which, like a light coating, surrounds our globe in every part. It shares the rotatory motion of the globe (30), and would remain fixed relatively to terrestrial objects, but for local circumstances, which produce winds, and are constantly disturbing its equilibrium.

The existence of this gaseous mass is proved by the winds, which incessantly blow on the surface of the earth ; by the flight of birds, and by the suspension of clouds.

Besides the oxygen and nitrogen of which the air is composed, it also contains a quantity of aqueous vapour, which varies with the temperature, the season, the locality, and the direction of the winds. The mean amount of this in London is from 5 to 6 grains in a cubic foot of air.

It further contains from 3 to 6 parts in 10,000 of carbonic acid. This arises from the respiration of man and animals, from the decay of organic matter, and from the combustion of wood and coal. This latter cause of the production of carbonic acid increases every year. It has been calculated that in Europe alone about 104 milliards of cubic yards of carbonic acid are every year sent into the atmosphere from this source. This mass of gas is equal to what would be produced by 500 millions of individuals, each by the act of respiration converting 154 grains of carbon into carbonic acid every hour.

Notwithstanding this enormous continual production of carbonic acid on the surface of the globe, the composition of the atmosphere does not vary ; for plants in the process of vegetation decompose the carbonic acid, assimilating the carbon, and restoring to the atmosphere the oxygen which is being continually consumed in the processes of respiration and combustion.

Thus, by a natural harmony, the atmosphere retains an almost uniform quantity of this gas, so that there seems no fear of its accumulating to such an extent as to be injurious to the human species.

116. **Atmospheric pressure.**—Having seen that air has weight, it is easy to conceive that the great mass of air which constitutes the atmosphere must exert a great pressure on the surface of the earth, and on all bodies found there. This pressure is called the *atmospheric pressure.* It necessarily decreases as we ascend in the atmosphere ; for if we conceive the atmosphere resolved into horizontal layers superposed on each other, it is clear that the lower layers which support the weight of the whole atmosphere are the most compressed and the most dense ; while the higher layers are less and less compressed, and therefore less and less dense. This is expressed by saying that they are more *rarefied* or more *rare.* In saying that 100 cubic inches of air weighed 31 grains, it was understood that air at the sea level was referred to ; at any greater height this volume of air would weigh less.

The pressure of the atmosphere may be demonstrated by a number of experiments, among which are the following :—

117. **Crushing force of the atmosphere.**—On one end of a stout glass cylinder, about 5 inches high, and open at both ends, a piece of bladder is tied quite air-tight. The other end, the edge of which is ground and well greased, is pressed on the plate of the air-pump (fig. 98). The bladder is pressed downwards by the weight of the atmosphere, and is pressed upwards by the expansive force of the air in the cylinder. These two pressures at first counterbalance each other—the bladder is not pressed in either direction ; but as soon as the internal air is removed from the vessel, by working the air-pump, the bladder is depressed by the weight of the atmosphere above it, and finally bursts with a loud report caused by the sudden entrance of the air.

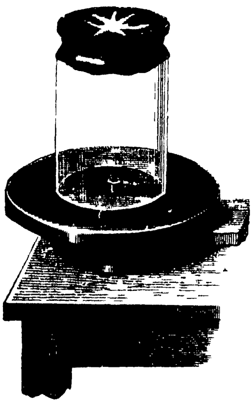


Fig. 98.

118. **Magdeburg hemispheres.**—The preceding experiment only serves to illustrate the downward pressure of the atmosphere. By means of the *Magdeburg hemispheres* (fig. 99), the invention of which is due to Otto von Guericke, burgomaster of Magdeburg, it can be shown that the pressure acts in all directions. This apparatus consists of two hollow brass hemispheres of 4 to 4½ inches

diameter, the edges of which are made to fit tightly, and are well greased. One of the hemispheres is provided with a stopcock, by which it can be screwed on the air-pump, and on the other there is a handle. As long as the hemispheres contain air they can be separated without any difficulty, for the external pressure of the atmosphere is counterbalanced by the elastic force of the air in the interior. But when the air in the interior is pumped out by means of the air-pump, the hemispheres cannot be separated without a powerful effort (fig. 100); and as this is the case in whatever position they are held, it follows that the atmospheric pressure is transmitted in all directions.

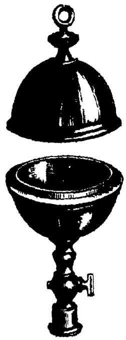


Fig 99.

We shall presently see (121) that the pressure of the atmosphere on a square inch is equal to that of a weight of about 15 lbs. Hence if, in the above experiment, the area, not of each of the hemispheres, but of the

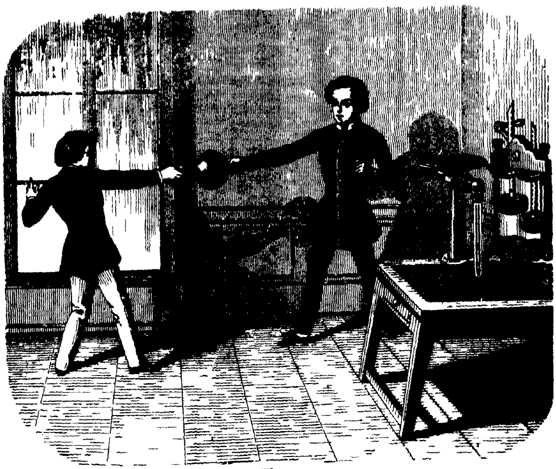


Fig. 100.

circle along which they are pressed, is ten square inches, the force by which they are pressed together is 150 lbs., and this force would be required to separate them.

Otto von Guericke, the inventor of this apparatus, constructed hemispheres the internal diameter of which was about 2 feet; when applied against each other and exhausted, twelve horses, six pulling at each hemisphere, were required to separate them.

DETERMINATION OF THE ATMOSPHERIC PRESSURE. BAROMETERS.

119. **Torricelli's experiment.**—The above experiments demonstrate the existence of the atmospheric pressure, but they give no indications as to its amount. The following experiment, which was first made in 1643 by Torricelli, a pupil of Galileo, not merely proves the pressure of the atmosphere, but also gives an exact measure of its weight.

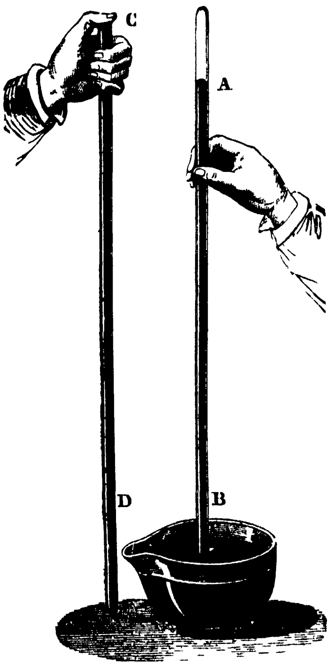


Fig. 101.

A glass tube is taken, about a yard long, and a quarter of an inch internal diameter (fig. 101). It is sealed at one end, and is quite filled with mercury. The aperture C being closed by the thumb, the tube is inverted, the open end placed in a small mercury trough, and the thumb removed. The tube being in a vertical position, the column of mercury sinks, and, after oscillating some time, it finally comes to rest at a height, A, which at the level of the sea is about thirty inches above the mercury in the trough. The mercury is raised in the tube by the pressure of the atmosphere on the mercury in the trough. There is no opposing pressure inside the tube on the mercury, because it is closed. But if the end of the tube be opened, the atmosphere will press equally inside and outside the tube, and the mercury will sink to the level of that in the trough. It has been shown in article 90 that the heights of two columns of liquid in communication with each

other are inversely as their densities; and hence it follows that the pressure of the atmosphere is equal to that of a column of mercury, the height of which is thirty inches. That the mercury sank in the first case was due to its weight being greater than the pressure of the atmosphere. If, however, the weight of the atmosphere diminishes, the height of the column which it can sustain must also diminish.

120. **Pascal's experiments.**—Pascal, who wished to prove that the force which sustained the mercury in the tube was really the pressure of the atmosphere, made the following experiments:—i. If it were the case, he reasoned, the column of mercury ought to descend in proportion as we ascend in the atmosphere (116). He accordingly requested one of his relatives to repeat Torricelli's experiment on the summit of the Puy de Dôme in Auvergne. This was done, and it was found that the mercurial column was about three inches lower there, thus proving that it is really the weight of the atmosphere which supports the mercury, since, when this weight diminishes, the height of the column also diminishes. ii. Pascal repeated Torricelli's experiment at Rouen, in 1646, with other liquids. He took a tube closed at one end, nearly 40 feet long, and, having filled it with water, placed it vertically in a vessel of water, and found that the water stood in the tube at a height of 34 feet; that is, 13·6 times as high as mercury. But since mercury is 13· times as heavy as water, the weight of the column of water was exactly equal to that of the column of mercury in Torricelli's experiment, and it was consequently the same force, the pressure of the atmosphere, which successively supported the two liquids. Pascal's other experiments with oil and with wine gave similar results. He found, for instance, that a column of oil stood at a height of about 37 feet.

121. **Amount of the atmospheric pressure.**—Let us assume that the tube in the above experiment is a cylinder, the cross-section of which is equal to a square inch; then, since the height of the mercurial column in round numbers is 30 inches, the column will contain 30 cubic inches, and as a cubic inch of mercury weighs $252·5 \times 13·6 = 3433·5$ grains $= 0·49$ of a pound (106), the pressure of such a column on a square inch of surface is equal to 14·7 pounds. In round numbers the pressure of the atmosphere is taken at 15 pounds on the square inch. A surface of a foot square contains 144 square inches, and therefore the pressure upon it is equal to 2,160 pounds, or nearly a ton.

A gas or a liquid which acts in such a manner that a square

inch of surface is exposed to a pressure of 15 pounds, is said to exert a pressure of *one atmosphere*. If, for instance, the elastic force of the steam of a boiler is so great that each square inch of the internal surface is exposed to a pressure of 90 pounds ($= 6 \times 15$), we say it is under a pressure of six atmospheres.

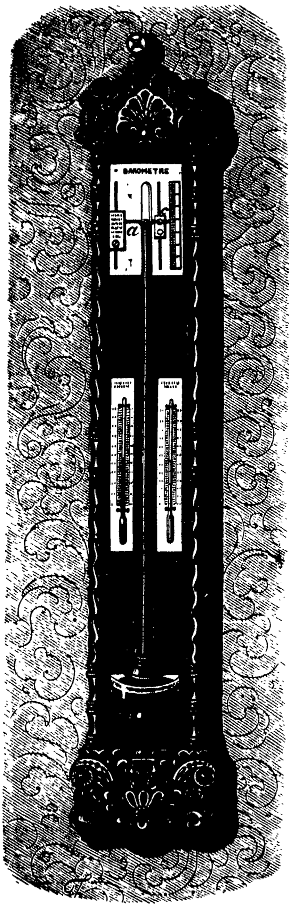


Fig. 102.

122. **Different kinds of barometers.**—The instruments used for measuring the atmospheric pressure are called *barometers*, from two Greek words which signify *measure of weight* (air, of course, being understood). In ordinary barometers, the pressure is measured by the height of a column of mercury, as in Torricelli's experiment; the barometers which we are about to describe are of this kind. But there are barometers without mercury, one of which, the aneroid (138), is remarkable for its simplicity and portability.

123. **Cistern barometer.**—Ordinary barometers are classed as *syphon* and *cistern* barometers. Fig. 102 represents the usual form of the cistern barometer. It consists of a glass tube, *ai*, closed at one end, about thirty-three inches long, and about half an inch in diameter. The tube is filled with mercury, and then its open end is inverted in mercury contained in a glass vessel, A, of a peculiar shape; only the front half of this is visible, the other being fixed in a mahogany board which supports the whole barometer. The bottom of the cistern forms a spherical well, which is filled with mercury, and in which

the tube *ai* is immersed. The tube is not fixed tightly in the neck, so that the atmospheric pressure is freely transmitted to the mercury of the bath, and thus supports the column of mercury *ai*. If the pressure increases, the mercury rises, if it decreases the mercury sinks.

At the top of the tube on the right is a scale divided in inches to measure the height of the mercury in the tube. The graduation starts from the zero, which is level with the mercury in the bath. Hence, if the top of the mercury at *a* stands at thirty inches, for instance, this signifies that the height of a column of mercury is thirty inches. Only a portion of the scale is given, since, for ordinary purposes, the variations of the atmospheric pressure are within a very few inches. Where greater variations occur, as in the use of the barometer for measuring heights, the graduated part must be longer.

It will be observed that the starting-point of the graduation, the zero, is at the level of the mercury in the cistern. But the zero of the scale does not always correspond to the level of the mercury in the cistern. For as the atmospheric pressure is not always the same, the height of the mercurial column varies; sometimes mercury is forced from the cistern into the tube, and sometimes from the tube into the cistern, so that, in the majority of cases, the graduation of the barometer does not indicate the true height. To diminish this source of error, the cistern has the form represented in fig. 102. Its upper part, that corresponding to the level of the mercury, is about four inches in diameter; so that, whether the mercury passes from the cistern into the tube, or from the tube into the cistern, as it is spread over a large surface the variations in the level are very small and may be neglected.

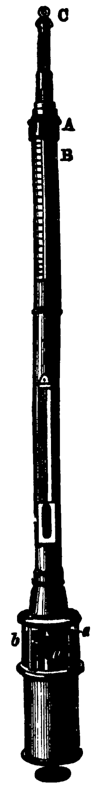


Fig. 103.

To complete this description, it may be added, that on the scale is a small index, *c*, sliding along a vertical rod. When made level with the mercury this index points on the one side to the divisions on the graduated scale, and on the other side to certain descriptions, the use of which will be afterwards stated (129). In the middle of the tube are two thermometers, one with a Fahrenheit and the other with a Centigrade graduation.

124. **Fortin's barometer.**—*Fortin's barometer* (fig. 103) differs from that just described, in the shape of the cistern. The base

of the cistern is made of leather, and can be raised or lowered by means of a screw; this has the advantage that a constant level can be obtained, and also that the instrument is made more portable. For, in travelling, it is only necessary to raise the leather until the mercury, which rises with it, quite fills the cistern; the barometer may then be inclined, and even inverted, without any fear that a bubble of air may enter, or that the shock of the mercury may crack the tube.

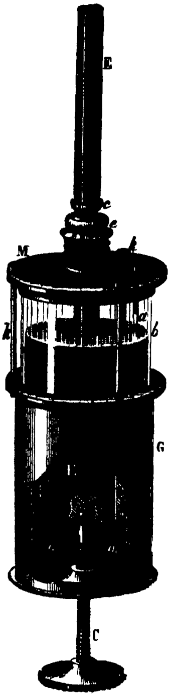


Fig 104

Fig. 104 shows the construction of the cistern. It consists of a glass cylinder *b*, which allows the mercury to be seen; the bottom of the cylinder is cemented to a box-wood cylinder, *zz*, on which is firmly fixed at *ii* the chamois leather *mn*, which is the base of the cistern. At the bottom of the leather is a small wooden button, *x*, against which the screw C works, by which it is raised or lowered This screw works in the bottom of a brass cylinder, G, which is fastened on the glass cylinder. At the top of the cistern there is a small ivory pointer, *a*, the point of which exactly corresponds to the zero on the scale. The upper part of the cistern is closed by buckskin, *ce*, which is fastened to the barometer tube, E, and to a tubulure in the wooden disc, which covers the cistern. The barometer tube is drawn out at the open end, which is immersed in the mercury. The atmospheric pressure is transmitted through the pores of the leather. In using this barometer, the mercury is first made level with the point *a*, which is effected by turning the screw C either in one direction or the other. In this manner the distance of the top, B, of the column of mercury from the ivory point *a*, gives exactly the height of the barometer. For the graduation is measured from the point *a*. Lastly, the lower part of the cistern is enclosed in a brass case, which is connected with a lid by three screws *k*, *k*, *k*. To the cistern is screwed a long brass case, which encloses the whole of the tube, as seen in fig. 105. At the top of this case there are two longitudinal slits, on opposite sides, so that the level of the mercury, B, is seen. The scale on the case is graduated in millimetres or

in inches. An index, A, moved by the hand, gives, by means of a vernier, the height of the mercury to $\frac{1}{10}$ of a millimetre. At the bottom of the case is affixed a thermometer to indicate the temperature.

125. **Gay-Lussac's syphon barometer.**—The syphon barometer has no cistern, but consists of a bent glass tube (fig. 105), one of the branches of which is much longer than the other. The longer branch, which is closed at the top, is filled with mercury as in the cistern barometer, while the shorter branch, which is open, serves as a cistern. The difference between the two levels is the height of the barometer.


Fig. 105.


Fig. 106.

Fig. 107.

Fig. 105 represents the syphon barometer as modified by Gay-Lussac. In other to render it more available for travelling by preventing the entrance of air he joined the two branches by a capillary tube ; when the instrument is inverted (fig. 106), the tube always remains full in virtue of its capillarity, and air cannot penetrate into the longer branch, which of course, is absolutely necessary. A sudden shock, however, might separate the mercury and admit some air. To avoid this, Bunten introduced an ingenious modification into the apparatus. The longer branch, A, is drawn out to a fine point, and is joined to a tube, B, of the form represented in fig. 107. By this arrangement, if air passes through the capillary tube, it cannot penetrate the drawn-out extremity of the longer branch, but lodges in the upper part of the enlargement B. In this position it does not affect the observation, since the vacuum is always at the upper part of the tube ; it is moreover, easily removed.

In Gay-Lussac's barometer the shorter branch is closed, but there is a very minute hole in the side *i*, fig. 107, through which the atmospheric pressure is transmitted.

The barometric height is determined by means of two scales, fig. 108, which have a common zero at the middle of the longer branch, and are graduated in contrary directions, the one from the middle to *a*, and the other from the middle to *b*, either on the tube itself, or on brass rules fixed parallel to the tube. Two sliding indexes are moved until they correspond to the levels of the mercury in *a* and *b*. The total height of the barometer *ab* is the sum of the distances from the middle to *a* and *b* respectively.

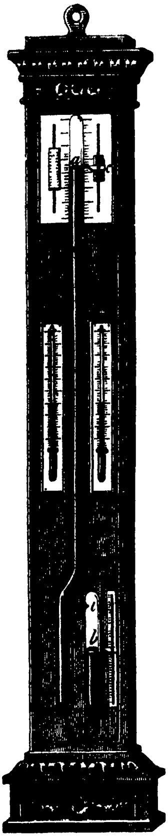


Fig. 108.

126. **Precautions in reference to barometers.**—In constructing barometers, mercury is chosen in preference to any other liquid. For being the densest of all kinds it stands at the least height. When the mercurial barometer stands at thirty inches, the water barometer would stand at about thirty-four feet. It also deserves preference because it does not moisten glass. It is necessary that the mercury be pure and free from oxide; otherwise it adheres to the glass and tarnishes it. Moreover, if it is impure, its density is different, and the height of the barometer is too great or too small. Mercury is purified, before being used for barometers, by treatment with dilute nitric acid, and by distillation.

The space at the top of the tube (figs. 101 and 108), which is called the *Torricellian vacuum*, must be quite free from air and from aqueous vapour, for otherwise either would depress the mercurial column. Now, glass tubes always condense aqueous vapour on their surface (66). Under the ordinary pressure of the atmosphere this layer of moisture adheres to the glass; but in a vacuum, where there is no pressure, it escapes, and there is formed a mixture of air and aqueous vapour which depresses the mercurial column.

The air and moisture can only be got rid of by boiling the mercury in the tube. To obtain this result a small quantity of pure mercury is placed in the tube and boiled for some time, fig. 109.

It is then allowed to cool, and a further quantity, previously warmed, added, which is boiled, and so on, until the tube is quite full; in this manner the moisture and the air which adhere to the sides of the tube pass off with the mercurial vapour. The bulb at the end is placed there to collect the mercury which may distil over. It is afterwards removed.

A barometer is free from air and moisture if, when it is inclined, the mercury strikes with a sharp metallic sound against the top of the tube. If there is air or moisture in it, the sound is deadened.

127. **Variations in the height of the barometer.**—When the barometer is observed for several days, its height is found to vary in the same place, not only from one day to another, but also during the same day. The extent of these variations—that is, the difference between the greatest and the least height—is different in

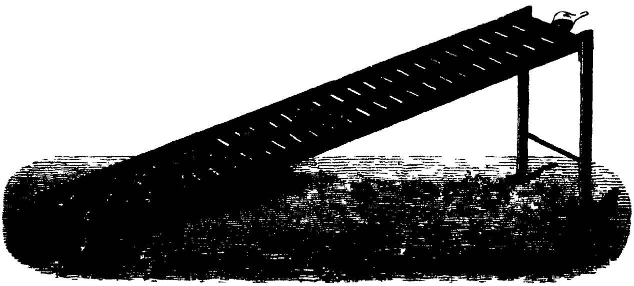


Fig. 109

different places. It increases from the equator towards the poles. The greatest variations are observed in winter.

The *mean daily height* is the height obtained by dividing the sum of 24 successive hourly observations by 24. In our latitudes, the barometric height at noon corresponds to the mean daily height.

The *mean monthly height* is obtained by adding together the mean daily height for a month, and dividing by thirty.

The *mean yearly height* is similarly obtained.

Under the equator, the mean annual height at the level of the sea is $0^{m}{\cdot}758$, or 29·14 inches. It increases from the equator, and between the latitudes 30° and 40° it attains a maximum of $0^{m}{\cdot}763$, or 30·04 inches. In lower latitudes it decreases, and in Paris it does not exceed $0^{m}{\cdot}7568$, or 29·79 inches.

The general mean at the level of the sea is $0^{m}.761$, or 29·96 inches. The mean monthly height is greater in winter than in summer, in consequence of the cooler atmosphere.

Two kinds of variation are observed in the barometer: 1st, the *accidental variations* or changes, which present no regularity; they depend on the seasons, the direction of the winds, and the geographical position, and are common in our climates; 2nd, the *daily variations*, which are produced periodically at certain hours of the day.

At the equator, and between the tropics, no accidental variations are observed; but the daily variations take place with such regularity that a barometer may serve to a certain extent as a clock. The barometer sinks from midday till towards four o'clock; it then rises, and reaches its maximum at about ten o'clock in the evening. It then again sinks, and reaches a second minimum towards four o'clock in the morning, and a second maximum at ten o'clock.

In the temperate zones there are also daily variations, but they are detected with difficulty, since they occur in conjunction with accidental variations. The hours of the maxima and minima appear to be the same in all climates, whatever be the latitude; they merely vary a little with the seasons.

128. **Causes of barometric changes.**—It is observed that the course of the barometer is generally in the opposite direction to that of the thermometer; that is, that when the temperature rises the barometer falls, and *vice versâ*; which indicates that the barometric changes at any given place are produced by the expansion or contraction of the air, and therefore by its change in density. If the temperature were the same throughout the whole extent of the atmosphere, no currents would be produced, and at the same height the atmospheric pressure would be everywhere the same. But when any portion of the atmosphere becomes warmer than the neighbouring parts, its specific gravity is diminished, and it rises and passes away through the upper regions of the atmosphere; whence it follows that the pressure is diminished, and the barometer falls. If any portion of the atmosphere retains its temperature, while the neighbouring parts become cooler, the same effect is produced; for in this case, too, the density of the first-mentioned portion is less than that of the others. Hence also, it usually happens that an extraordinary fall of the barometer at one place is counterbalanced by an extraordinary rise at another place. The daily variations appear to result from the expansions

and contractions, which are periodically produced in the atmosphere by the heat of the sun during the rotation of the earth.

129. **Relation of barometric changes to the state of the weather.**—It has been observed that, in our climate, the barometer is generally above 30 inches in fine weather, and is below this point when there is rain, snow, wind, or storm, and also, that for any given number of days on which the barometer stands at 30 inches, there are as many fine days as rainy days. From this coincidence between the height of the barometer and the state of the weather, the following indications have been marked on the barometer, counting by thirds of an inch above and below 30 inches :—

Height.	State of the weather.
31 inches	Very dry.
$30\frac{2}{3}$ "	Settled weather.
$30\frac{1}{3}$ "	Fine weather.
30 "	Variable.
$29\frac{2}{3}$ "	Rain or wind.
$29\frac{1}{3}$ "	Much rain.
29 "	Storm.

In using the barometer as an indicator of the state of the weather, we must not forget that it really only serves to measure the weight of the atmosphere and that it only rises and falls as this weight increases or diminishes ; and although a change of weather frequently coincides with a change in the pressure, they are not necessarily connected. This coincidence arises from meteorological conditions peculiar to our climate, and does not always occur. That a fall in the barometer usually precedes rain in our latitudes is caused by the position of Europe. The most frequent winds are the south-west and north-east. The former coming to us from the equatorial regions are warmer and lighter. They often, therefore, blow for hours or even days in the higher regions of the atmosphere before manifesting themselves on the surface of the earth. The air is therefore lighter, and the pressure lower. Hence a fall of the barometer is a probable indication of the south-west winds, which gradually extend downwards, and, reaching us after having traversed large tracts of water, are charged with moisture, and bring us rain.

The north-east blows simultaneously above and below, but the hindrances to the motion of the current on the earth, by hills, forests, and houses, cause the upper current to be somewhat in

advance of the lower one, though not so much as the south-west wind. The air is therefore somewhat heavier even before we perceive the north-east, and a rise of the barometer affords a forecast of the occurrence of this wind, which, as it reaches us after having passed over the immense tracts of dry land in Central and Northern Europe, is mostly dry and fine.

When the barometer rises or sinks slowly—that is, for two or three days—towards fine weather or towards rain, it has been found, from a great number of observations, that the indications are then extremely probable. Sudden changes in either direction indicate bad weather or wind.

130. **Wheel Barometer.**—Figure 110 represents the principle of the *wheel barometer*, which was invented by Hooke; it is a syphon barometer, and in the shorter leg there is a float, *a*, which rises and falls with the mercury. A string attached to this float passes round a pulley, and at the other end there is another and somewhat lighter weight. A needle fixed to the pulley moves round a graduated circle, on which is marked *variable*, *rain*, *fine weather*, etc. When the pressure varies the float rises or sinks, and moves the needle round to the corresponding points on the scale.

Fig. 110.

The barometers ordinarily met with in houses, and which are called *weather glasses*, are of this kind. They are, however, of little use, for two reasons. The first is that they are neither very delicate nor precise in their indications. The second, which applies equally to all barometers, is, that those commonly in use in this country are made in London, and the indications, if they are of any value, are only so for a place at the same level and of the same climatic conditions as London. Thus a barometer standing at a certain height in London would indicate a certain state of weather, but if removed to Shooter's Hill it would stand half an inch lower and would indicate a different state of weather. As the pressure differs with the level and with geographical conditions, it is necessary to take these into account if exact data are wanted.

131. **Weight Barometer.**—Great attention has been paid of late years to the systematic observations of meteorological instruments, and figure 111 represents the essential parts of a self-acting

arrangement by which changes in the barometric height may be observed and recorded. It is an application of what is called a *weight barometer*.

The barometer tube is much wider at the top B, and the other end A, which dips in mercury, is drawn out to a fine point. The barometer is suspended by a stirrup, C, to an arm, D, of a scale beam. The other arm, F, is bent downwards, and is provided with a sliding weight, by which the barometer may be counterpoised. To the beam is fixed a spring indicator, K, which has a pencil, R, at the end. This presses against a strip of paper, PP, which, by means of a clockwork arrangement not represented in the figure, is moved at a regular and definite rate.

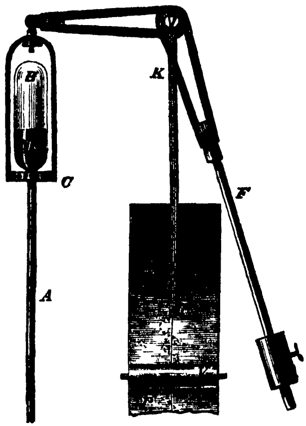


Fig. 111.

If now the barometer is stationary, and the clockwork is in motion, the pencil, R, will describe a straight line on the paper as it moves. If, however, the pressure of the atmosphere increases, the column of mercury becomes heavier, for it is longer, the scale beam sinks somewhat on the side of D, and the index, R, moves to the left. The opposite is the case when the pressure of the atmosphere decreases. Hence, if the pressure varies, the pencil will trace out a curve on the paper; and, by calculations based on the construction and dimensions of the apparatus, which are determined once for all for each instrument, the numerical significance of the curve is obtained at a glance.

132. **Determination of the heights of places by the barometer.**—One of the most important of the uses of the barometer has been its application to the measurement of the heights of places above the sea level. For if we suppose the atmosphere divided into horizontal layers of equal thickness, a hundred for instance, a barometer at the sea level would support the weight of a hundred of these layers; and, as we have seen (119), would be at rest when its height was thirty inches. If it were raised in the atmosphere to the height of ten such layers, it would now only support the weight of ninety such layers; and the mercury would

therefore necessarily sink. It would sink still further if it were raised to the twentieth layer, and so on to the limit of the atmosphere, if that were possible. There it would be under no pressure, and the level of the mercury in the tube and in the cistern would be the same.

As the mercury sinks in proportion as we rise in the atmosphere, we might, from the amount by which it is lower, deduce the height above the sea level. If air had everywhere the same density up to the extreme limit of the atmosphere, the calculation would be very simple; for as mercury is about 10,500 times as heavy as air, an inch of the barometer would correspond to a column of air of about 875 feet; hence, in ascending a mountain, a diminution of an inch in the height of the barometer would correspond to an ascent of about 875 feet. But the density of the air decreases as we ascend, for the layers of air necessarily support a less weight; hence, the measurement of the heights by the barometer is not so simple as we have supposed. Very complete tables have, however, been constructed, by which the difference in height between any two places may be readily ascertained, if we know the corresponding heights of the barometer. For small elevations we may assume that an ascent of 900 feet produces a depression of an inch in the height of the barometer. For measuring heights by the barometer the aneroid (138) is extremely convenient.

On the top of the Rigi the density of the air is only about $\frac{11}{14}$ of its density at the sea level; or, what amounts to the same thing, 11 cubic feet of air at the sea level weighs as much as 14 cubic feet taken from the top of the mountain.

If a barometer be taken from the cellar to the fourth or fifth story of a large house, it will be found to stand $\frac{1}{10}$ of an inch or so lower.

133. **Height of the atmosphere.**—In virtue of the expansive force of the air, it might be supposed that the molecules would expand indefinitely into the planetary spaces. But, in proportion as the air expands, its expansive force decreases, and is further weakened by the low temperature of the upper regions of the atmosphere, so that at a certain height the expansive force, which separates the molecules, is balanced by the action of gravity which draws them towards the centre of the earth. It is therefore concluded that the atmosphere is limited. We may get an idea of the relation between the dimensions of the earth and its atmosphere, by imagining a globe one foot in diameter covered by a sheet of paper about $\frac{1}{12}$ of an inch in thickness.

From the weight of the atmosphere, and its decrease in density, its height has been calculated at from 30 to 40 miles. Observations of shooting stars make it probable that they become visible at a height of from 90 to 130 miles. As their luminosity is ascribed to the heat developed by their friction against the atmosphere, we must suppose that at this great height there is some atmosphere, though it is so attenuated as to be in effect a complete vacuum.

From observations on the twilight arc at Rio Janeiro, Liais estimated the height of the atmosphere at between 198 and 212 miles—considerably higher, therefore, than what has hitherto been believed.

134. **The pressure of the atmosphere is transmitted in all directions.**—The atmosphere, like any other mass of fluid (77), must necessarily transmit its pressure in all directions, upwards and laterally as well as downwards. A striking instance of this is seen in the Magdeburg hemispheres (118), and the following experiment furnishes another illustration of this point.

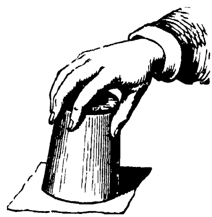


Fig. 112

A tumbler full of water is carefully covered with a sheet of paper, which is kept in position by one hand, while with the other the tumbler is inverted. Removing then the hand which held the paper, the water does not fall out, both water and paper being kept in position by the upward pressure (fig. 112). The object of the paper is to present a flat surface of water, for otherwise the water would divide and would allow air to enter, and then the experiment would fail.

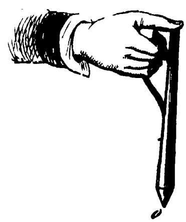


Fig. 113.

The use of the *wine-tester* also depends on the pressure of the atmosphere. It consists of a tin tube (fig. 113) terminating at the bottom in a small cone, the end of which, *o*, is open; at the top there is a small aperture, which is closed by the thumb. The two ends being open, the tube is immersed in the liquid to be tested; closing then the upper end by the thumb, as shown in the figure, the tube is withdrawn, and remains filled in consequence of the pressure at *o*. But if the thumb be withdrawn, the pressure is transmitted both upwards and downwards, and the liquid flows out in obedience to the action of gravity.

135. **Pressure supported by the human body.**—The surface of the body of a man of middle size is about 16 square feet; the pressure, therefore which a man supports on the surface of his body is 37,560 pounds, or upwards of 16 tons. Such an enormous pressure might seem impossible to be borne; but it must be remembered that in all directions there are equal and contrary pressures which counterbalance one another. It might also be supposed that the effect of this force, acting in all directions, would be to press the body together and crush it. But the solid parts of the skeleton could resist a far greater pressure ; and as to the liquids contained in the organs and vessels, it is clear from what has been said about liquids (77) that they are virtually incompressible. The gases, too, are compressed by the weight of the atmosphere, but they resist it in virtue of their elasticity. They are, in short, like a bottle full of air. The sides of the latter are pressed in by the weight of the atmosphere; but they can stand this, however thin their walls, for the pressure of the gas from within quite counterbalances that which presses on the outside.


Fig. 114.

The following experiment (fig. 114) illustrates the effect of atmospheric pressure on the human body. A glass vessel open at both ends, being placed on the plate of the air-pump, the upper end of the cylinder is closed by the hand and a vacuum is made. The hand then becomes pressed by the weight of the atmosphere, and can only be taken away by a great effort. And as the elasticity of the gas contained in the organs is not counterbalanced by the weight of the atmosphere, the palm of the hand swells, and blood tends to escape from the pores.

The operation of *cupping* in medicine is an application of the effect of removing the atmospheric pressure from the human body. The human mouth applied upon any part, in the action of sucking, is a kind of cupping apparatus. The mouth of the leech is such an apparatus with one lancet.

CHAPTER II.

MEASUREMENT OF THE ELASTIC FORCE OF GASES.

136. **Boyle's law.**—The law of the compressibility of gases was discovered by Boyle in 1662 and subsequently in 1679, though independently by Mariotte. It is in England commonly called Boyle's law, and, on the Continent, Mariotte's law. It is as follows:—

'*The temperature remaining the same, the volume of a given quantity of gas is inversely as the pressure which it bears.*'

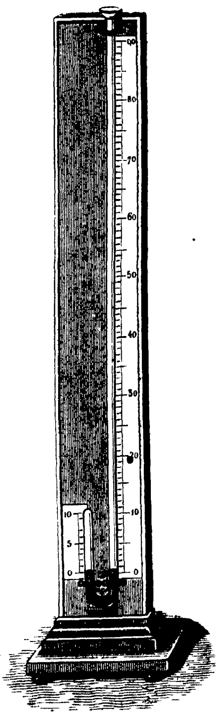


Fig. 115.

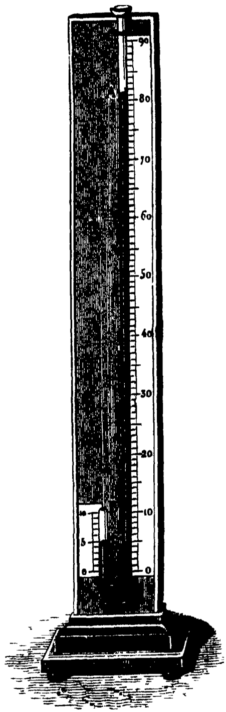


Fig. 116.

This law is easily verified by means of an apparatus called *Boyle's tube* (fig. 115). It consists of a long glass tube fixed to a vertical support: it is open at the top; and the other end, which is bent into a short vertical leg, is closed. On the shorter leg there is a scale which indicates equal *capacities*; the scale against the long leg

gives the heights. The zero in both scales is in the same horizontal line.

A small quantity of mercury is poured into the tube, so that its level in both branches is at zero, which is effected without much difficulty. The air in the short leg is thus under the ordinary atmospheric pressure. If mercury be then poured into the longer tube, the volume of the air in the smaller tube is gradually reduced. If this be continued until it is only one half, that is, until it is reduced from 10 to 5, as shown in figure 117, and if the height of the mercurial column, CA, be now measured, it will be found to be exactly equal to the height of the barometer at the time of the experiment. The pressure of the column CA is therefore equal to an atmosphere, which, with the atmospheric pressure acting on the surface of the column at C, makes two atmospheres. Accordingly, by doubling the pressure, the volume of the gas has been diminished to one-half.

If mercury be poured into the longer branch until the volume of the air is reduced to one-third its original volume, it will be found that the distance between the level of the two tubes is equal to two barometric columns. The pressure is now three atmospheres, while the volume is reduced to one-third. Dulong and Petit have verified the law for air up to 27 atmospheres, by means of an apparatus analogous to that which has been described.

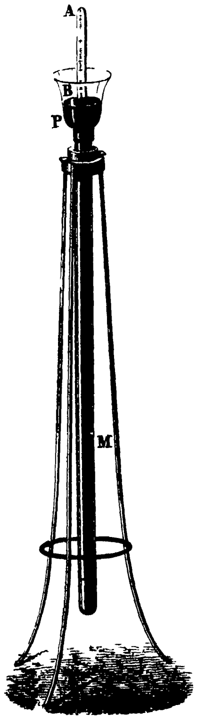


Fig. 117

Fig. 118

The law also holds good in the case of pressures of less than one atmosphere. To demonstrate this, mercury is poured into a graduated tube, until it is about two-thirds full, the rest being air. It is then inverted in a deep trough, PM, containing mercury (fig. 117), and lowered until the levels of the mercury inside and outside the

tube are the same, and the volume AB, which is then under a pressure of one atmosphere, is noted. The tube is then raised as represented in fig. 119, until the volume of the air, AC, is doubled. The height of the mercury in the tube above the mercury in the trough CD is then found to be exactly half the height of the barometer at the time of the experiment. Accordingly, for half the pressure, the volume has been doubled.

In the experiment with Boyle's tube, as the quantity of air remains the same, its density must obviously increase as its volume diminishes, and *vice versâ*. The law may thus be enunciated: '*For the same temperature the density of a gas is proportional to its pressure.*' Hence, since water is 773 times as heavy as air, under a pressure of 773 atmospheres air would be as heavy as water.

Until within the last few years Boyle's law was supposed to be absolutely true for all gases at all pressures; but several physicists have since observed that the gas is not rigorously exact, especially in the case of those gases which are most easily liquefied. They are more compressed than is required by the law. For air, Dulong and Arago investigated the pressure up to 27 atmospheres, and observed that the volume of air always diminished a little more than is required by Boyle's law. But as these differences were very small, they attributed them to errors of observation, and concluded that the law was perfectly exact, at any rate up to 27 atmospheres.

For ordinary pressures Boyle's law may be assumed to be exact for all gases.

137. **Manometers.**—*Manometers* are instruments for measuring the elastic force of gases or vapours. In all manometers the unit chosen is the pressure of one atmosphere, or thirty inches of mercury at the standard temperature, which, as we have seen (121), is nearly 15 lbs. to the square inch. The open-air *manometer* is represented in fig. 120 fixed against a board fastened to a wall and connected with a steam boiler. It consists of a glass tube about 20 feet in height, open at the top, and fixed at the other end to a glass bath, C, containing mercury. A long tube connects this with a boiler.

When the elastic force of the steam in the boiler is equal to the pressure of the atmosphere, it will counterpoise the weight of the atmosphere which is transmitted through the tube, and the level of the mercury is then the same in the tube and in the bath. At this level the number 1 is marked on the board. Then since a column of mercury 30 inches in height represents a pressure of an

atmosphere, the number 2 is marked at this height above 1 ; at a height of 30 inches above this the number 3 is marked, and so on, each interval of 30 inches representing an atmosphere. Thus, for instance, if the mercury has been forced up to 3½, as represented in the figure, that would indicate that the elastic force of the steam

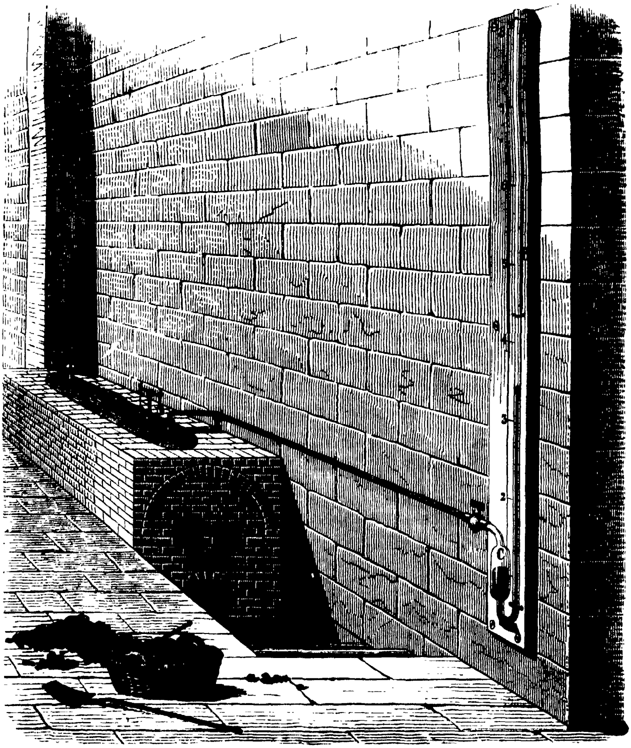


Fig. 119.

in the boiler is 3½ atmospheres ; so that, on each square inch of the inner surface of the boiler, there is a pressure of 3½ × 15 pounds, or 52½ pounds.

The manometer with *compressed air* is founded on Boyle's law ; it consists of a glass tube closed at the top (fig. 120), and filled with

dry air. It is firmly cemented in a small bath containing mercury. By a tubulure, this bath is connected with the closed vessel containing either the gas or vapour whose elastic force is to be measured.

In the graduation of this manometer, the quantity of air contained in the cube is such that, when the aperture communicates freely with the atmosphere, the level of the mercury is the same in the tube and in the bath. Consequently, at this level, the number 1 is marked on the scale to which the tube is affixed. As the

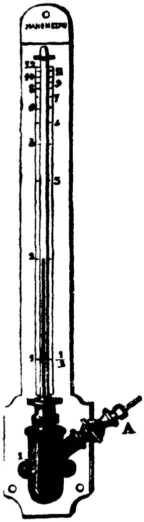


Fig. 120.

Fig. 121.

pressure acting through the tubulure A increases, the mercury rises in the tube, until its weight added to the elastic force of the compressed air is equal to the external pressure. It would consequently be incorrect to mark two atmospheres in the middle of the tube; for since the volume of the air is reduced to one-half, its elastic force is equal to two atmospheres, and, together with the weight of the mercury raised in the tube, is therefore more than two atmospheres. The position of the number is a little below the middle at such a height that the elastic force of the compressed air, together with the weight of the mercury in the tube, is equal to two

atmospheres. The exact position of the numbers 2, 3, 4, etc., on the manometer scale can only be determined by calculation.

138. **Aneroid barometer.**—This instrument derives its name from the circumstance that no liquid is used in its construction (ἀ, without, νηρός, moist). Fig. 121 represents one of the forms of these instruments constructed by Mr. Casella ; it consists of a cylindrical metal box. exhausted of air, the top of which is made of thin corrugated metal, so elastic that it readily yields to alterations in the pressure of the atmosphere.

When the pressure increases, the top is pressed inwards ; when, on the contrary, it decreases, the elasticity of the lid, aided by a spring, tends to move it in the opposite direction. These motions are transmitted, by delicate multiplying levers, to an index which moves over a scale. The instrument is graduated empirically, by comparing its indications, under different pressures, with those of an ordinary mercurial barometer.

The aneroid has the advantage of being portable, and can be constructed of such delicacy as to indicate the difference in pressure between the height of an ordinary table and the ground. It is hence much used in surveying and in determining heights in mountain ascents. But it is somewhat liable to get out of adjustment, especially when it has been subjected to great variations of pressure ; and its indications should from time to time be compared with those of a standard barometer.

MIXTURE AND SOLUTION OF GASES.

139. **Laws of the mixture of gases.**—We have seen that liquids, when they do not act chemically on each other, tend continually to separate, and to become superposed in the order of their densities. This is not the case with gases ; being under a continual tendency to expand, when they mix, their mixture is found to be subject to the following laws.

I. *Whatever their densities, gases mix in equal proportions in all parts of the vessel in which they are contained.*

II. *The elastic force of the mixture is equal to the sum of the elastic forces of the constituents.*.

The first law was shown experimentally by Berthollet, by means of an apparatus represented in fig. 122. It consisted of two glass globes provided with stopcocks, which could be screwed one on the other. The upper globe was filled with hydrogen, and the lower one with carbonic acid, which has 22 times the density of hydrogen.

The globes having been fixed together were placed in the cellars of the Paris Observatory, and the stopcocks were then opened, the globe containing hydrogen being uppermost. Berthollet found, after some time, that the pressure had not changed, and that, in spite of the great difference in density, the two gases had become uniformly mixed in the two globes. Experiments made, in the same manner, with other gases gave the same results, and it was found that the diffusion was more rapid in proportion as the difference between the densities was greater.

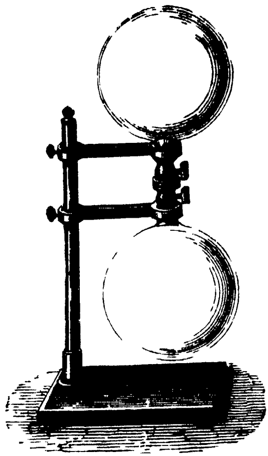


Fig. 122.

In accordance with this law, air being a mixture of nitrogen and oxygen, which are different in density, its composition should be the same in all parts of the atmosphere, which in fact is what has been observed.

This is not inconsistent with the fact that there may be local accumulations of gases, such as carbonic acid in deep pits; in such cases some cause is at work producing the gas in question faster than it diffuses.

Mixtures of gases come under Boyle's law, like simple gases, as has been proved for air (136), which is a mixture of nitrogen and oxygen.

140. **Mixture of gases and liquids. Absorption of gases.** —Water and many liquids possess the property of absorbing gases. Under the same conditions of pressure and temperature a liquid does not absorb equal quantities of different gases. At the ordinary temperature and pressure water dissolves $\frac{25}{1000}$ its volume of nitrogen, $\frac{46}{1000}$ its volume of oxygen, its own volume of carbonic acid, and 430 times its volume of ammoniacal gas.

The general laws of gas-absorption are the following :—

I. *For the same gas, the same liquid, and the same temperature, the weight of gas absorbed is proportional to the pressure.* This may also be expressed by saying that at all pressures the volume dissolved is the same; or that the density of the gas absorbed is in a constant relation with that of the external gas which is not absorbed.

Accordingly, when the pressure diminishes, the quantity of dissolved gas decreases. If a solution of a gas be placed under the air-pump and a vacuum created, the gas obeys its expansive force and escapes with effervescence.

The manufacture of aërated waters is a practical application of this law. By means of force pumps an excess of carbonic acid is dissolved in the water, and the solution is then preserved in carefully corked vessels. It is the carbonic acid dissolved in beer, in champagne, and in all effervescing liquids, which, rapidly escaping when the bottles are uncorked, produces the well-known report, and carries with it a greater or less quantity of the liquid.

II. *The quantity of gas absorbed is greater when the temperature is lower;* that is to say, when the elastic force of the gas is less.

III. *The quantity of gas which a liquid can dissolve is independent of the nature and of the quantity of other gases which it may already hold in solution.*

For instance, if a given volume of water be already saturated with oxygen, of which it dissolves about $\frac{1}{20}$ of its volume, it would still dissolve its own volume of carbonic acid if it were placed in an atmosphere of that gas.

CHAPTER III.

APPARATUS WHICH DEPEND ON THE PROPERTIES OF AIR.

141. **Air-pump.**—The air-pump is an instrument by which a vacuum can be produced in a given space, or rather by which air can be greatly rarefied, for an absolute vacuum cannot be produced by its means. It was invented by Otto von Guericke in 1650, a few years after the invention of the barometer.

Fig. 123 gives a perspective view of the pump, fig. 124 gives a detailed longitudinal section, and fig. 125 gives a cross section.

The pump consists of two stout glass barrels in which two pistons, P and Q, made of leather well soaked with oil, move up and down, and close the barrels air-tight. The pistons are fixed to two racks, A and B, working with a pinion K (fig. 125), which is moved by the handle MN, so that when one piston rises the other descends.

The two barrels are firmly cemented on the base, H, which is of brass; on this plate is a column, I, terminated by a plate, G. On this plate is a glass bell jar which is called the *receiver*. In the interior of the column is a conduit, which is prolonged below the base between the two barrels. It there branches in the shape of a T, terminating in two apertures, *a* and *b*, in the bottom of the cylinders. These apertures are conical, and are closed by two small conical valves; these latter are fixed to metal rods which work air-tight, but with gentle friction in the pistons. In the pistons is a cylindrical cavity communicating with the lower part of the pump by two apertures, *s* and *t* (fig. 125). These apertures are closed by small clack valves, kept in position by springs which surround each of the rods themselves. The four valves, *a*, *b*, *s*, *t*, open upwards.

These details being known, the working of the machine is readily understood. It is sufficient to consider what takes place in a single piston, fig. 124. The piston P being first at the bottom of its stroke, on rising it raises the rod which traverses it, and therewith the valve *a*, which remains open during the ascent. The

valve *t* which is in the piston, remains closed by the action of the spring and by the pressure of the atmosphere, which acts in the barrel through an aperture, *r*, in the cover. From this position of the two valves, it will be seen that, as the piston rises, the external

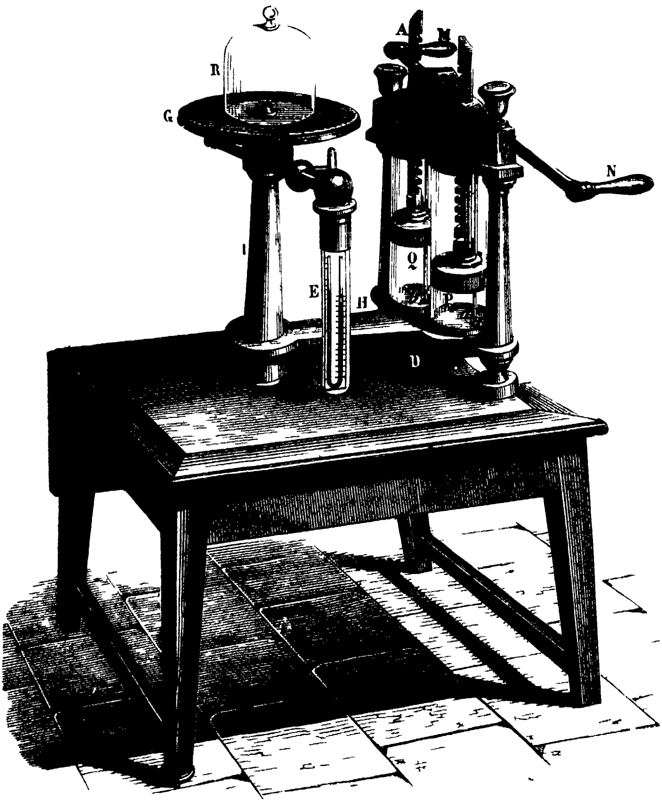


Fig 123

pressure of the atmosphere cannot act in the bottom of the barrel, but the air of the receiver, in virtue of its elasticity, expands and passes by the conduit, I and H, into the barrel. The receiver is still full of air, but it is more rarefied; it is less dense.

When the piston descends, the rod which bears the valve, *a*, descending with it, communication between the receiver and the barrel is cut off. The air in the barrel becomes more and more compressed, its elastic force increases, and finally overcomes the atmospheric pressure; so that the valve *t*, being pressed upwards by the elastic force of the air in the interior more strongly than it is pressed downwards by the atmosphere, is raised, and allows the air of the barrel to escape into the upper part of the barrel, and

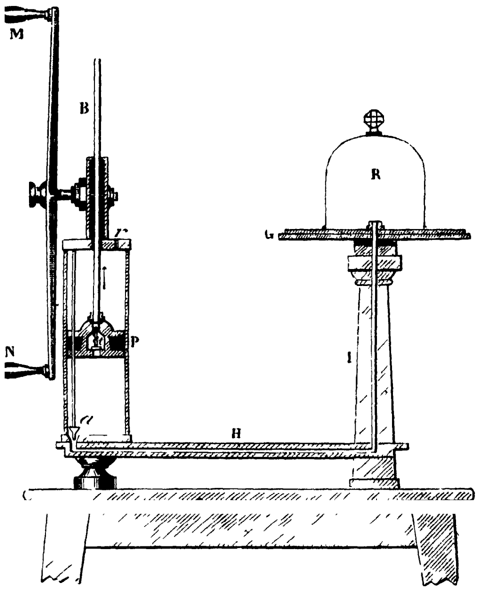


Fig 124

thence into the atmosphere. Thus a certain quantity of air has been removed. A fresh quantity is removed at a second stroke of the piston, another at the third, and so on. The air in the receiver is thus gradually more and more rarefied; yet all the air cannot be entirely extracted, for it ultimately becomes so rarefied, both in the receiver and in the barrel, that when the piston P is at the bottom of its stroke, the compressed gas below the piston has no longer

sufficient force to overcome the resistance of the atmosphere and force open the valve, *t*. The limit of rarefaction has then been attained, and it is useless to work the pump any longer.

What has been said in reference to one barrel applies also to the other. The machine will work with one; and the first air-pumps had but one. The advantage of having two is that the vacuum is more rapidly produced. The use of double-action air-pumps was first introduced by Hawksbee.

142. **Measurement of the degree of rarefaction in the receiver.**—Since a perfect vacuum cannot be obtained in the receiver, it is useful to have a means of ascertaining the degree of rarefaction at any particular time. This is effected by means of a glass cylinder, E, connected by a brass cap with the conduit in the column I (fig. 123). In this cylinder is placed a bent glass tube, closed at one end and open at the other. This is called the *air-pump gauge.* It is fixed against a plate, on which is a graduated scale. The closed branch being at first full of mercury, so long as the air in the receiver P and in the cylinder E has sufficient pressure, it sustains the mercury in the tube; the height of which is from six to eight inches. But as the pump is worked, the air becomes more and more rarefied, and has no longer the elastic force sufficient for retaining the column of mercury in the closed limb. It accordingly sinks in this limb and rises in the other. The greater the rarefaction, the smaller the difference of the level in the two limbs. They are, however, never exactly equal; that would correspond to a perfect vacuum. The mercury is always at least the $\frac{1}{20}$th of an inch higher in the closed branch. This is expressed by saying that a vacuum has been created within $\frac{1}{20}$th of an inch.

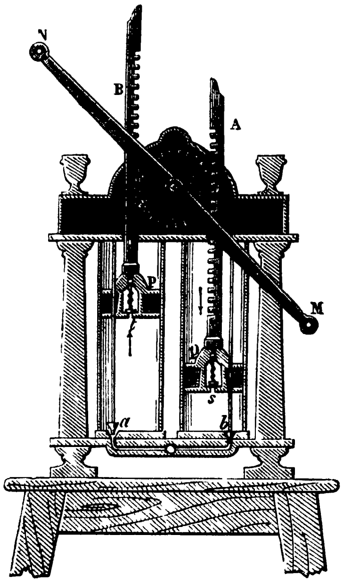


Fig. 125.

143. **Uses of the air-pump.**—A great many experiments with the air-pump have been already described. Such are the mercurial rain (fig. 1), the fall of bodies in vacuo (fig. 42), the bladder (fig. 96), the bursting of a bladder (fig. 98), the Magdeburg hemispheres (fig. 99), and the baroscope (fig. 144).

The *fountain in vacuo* (fig. 126) is an experiment made with the air-pump, and shows well the elastic force of the air. It is an elongated flask, A, with a stopcock at the base, provided with a tubulure which projects in the interior. Having screwed this flask on the plate of the air-pump, it is exhausted, the stopcock closed, and the apparatus is placed in a vessel of water, R. Opening then the stopcock, the atmospheric pressure on the water causes it to jet up by the tubulure, as shown in the drawing.

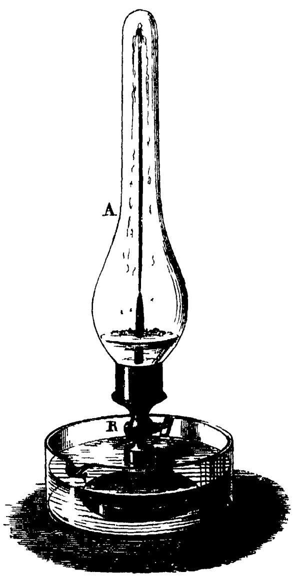


Fig. 126.

By means of the air-pump it may be shown that air, by reason of the oxygen it contains, is necessary for the support of combustion and of life. For if we place a lighted taper under the receiver and begin to exhaust the air, the flame becomes weaker as rarefaction proceeds, and is finally extinguished. Similarly an animal faints and dies if a vacuum is formed in a receiver under which it is placed. Mammalia and birds soon die in a vacuum. Fishes and reptiles support the loss of air for a much longer time. Insects can live several days in a vacuum.

144. **Application of the vacuum to the preservation of food.**—An important application has been made of the vacuum in preserving food. The germs present everywhere in air, under the influence of heat and moisture, make animal and vegetable matters rapidly ferment and putrefy; but if the air be removed from an enclosed vessel by exhausting, they may be kept fresh for many years.

Appert was the first, in 1809, to devise a means of preserving food in a vacuum, which consists in placing the substances to be

preserved in tin vessels, which are closed hermetically, and then heated in boiling water for some time; under the influence of heat the small quantity of oxygen left in the vessel is absorbed by the substance placed there, so that only nitrogen is present in the free state. Not only this, but the high temperature destroys the germs, which are the active agents in starting putrefaction. Substances properly prepared in this manner may be kept for years without alteration.


Fig. 128.

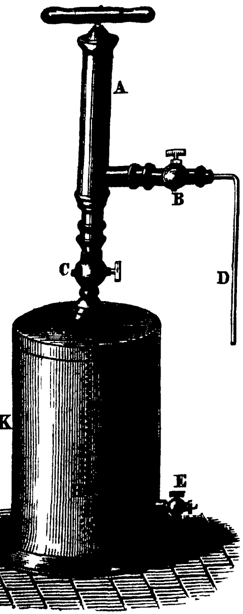


Fig. 127.

Appert's method is modified in England in the following manner. Instead of boiling the food while contained in the closed vessel, a small hole is left in the lid, through which escape the air and vapours produced during ebullition. When it is supposed that all the air has been expelled, a drop of melted lead is allowed to fall on the small hole in the cover which completely closes it. This method is practised on a large scale in preserving food and vegetables for the use of sailors, and also in preserving Australian meat, which is now consumed in large quantities.

145. **Condensing pump.**—The condensing pump is an apparatus for compressing air or any other gas. The form usually adopted is the following: In a cylinder A, of small diameter (fig. 127), there is a solid piston the rod of which is worked by the hand. The cylinder is provided with a screw, which fits into the receiver, K. Fig. 128 shows the arrangement of the valves, which are so constructed that the lateral valve, *o*, opens from the outside and the lower valve, *s*, from the inside.

When the piston descends, the valve *o* closes, and the elastic force of the compressed air opens the valve *s*, which thus allows the compressed air to pass into the receiver. When the piston ascends, *s* closes and *o* opens, and permits the entrance of fresh air, which

in turn becomes compressed by the descent of the piston, and so on.

This apparatus is chiefly used for charging liquids with gases. For this purpose the stopcock B is connected with a reservoir of the gas, by means of the tube D. The pump exhausts this gas, and forces it into the vessel K, in which the liquid is contained. This can be drawn off by the stopcock E. The artificial aërated waters are made by means of analogous apparatus; and one form of the condensing pump is used for testing and clearing gas pipes.

On a larger scale the same principle is applied in compressing air in sinking cylinders for the purpose of building piers under water: and it is also applied in the atmospheric railway brakes.

146. **Air-gun.**—This is an interesting application of the condensing pump. At the end of the receiver is a valve which opens inwards and allows air to enter, but not to escape. To this receiver is screwed a barrel as represented in fig. 129, in which a piston works. When the piston is at the bottom of the barrel, air can escape through two side holes, *a*. When the piston is pushed down, air cannot escape from the reservoir; the barrel is filled with a fresh supply, which is pressed into the receiver, and so forth.

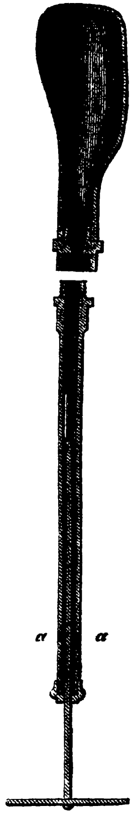


Fig. 129.

When the air in the receiver has been condensed, the charging barrel is unscrewed and a firing barrel screwed on. On touching a trigger (not represented in the figure) the valve is opened, a portion of air escapes, and projects the bullet; the valve is closed again at once. Thus, when once the air-gun is charged, several shots may be made in succession, though they become gradually weaker.

147. **Hiero's fountain.**—Hiero's fountain is an arrangement by which a jet may be obtained which lasts for some time. It derives its name from its inventor, Hiero, who lived at Alexandria 120 B.C., and depends on the elasticity of the air. It consists of a brass dish (fig. 130), and of two glass globes. The dish communicates with the lower part of the globe by a long tube; and another tube connects the two

globes. A third tube passes through the dish to the lower part of the upper globe. This tube having been taken out, the upper globe is partially filled with water, the tube is then replaced, and water is poured into the dish. The water flows through the long tube into the lower globe and expels the air, which is forced into

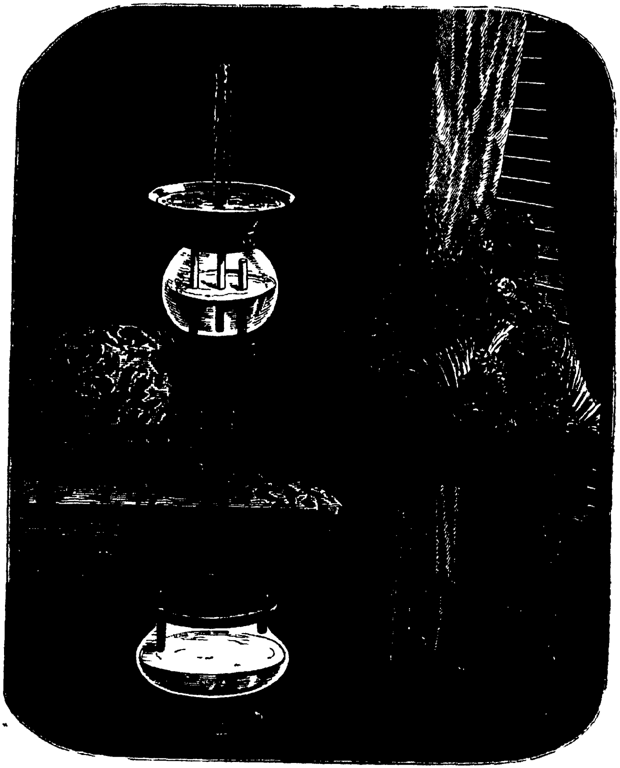


Fig 130.

the upper globe; the air thus compressed acts upon the water, and makes it jet out as represented in the figure. If it were not for the resistance of the atmosphere, and friction, the liquid would rise to a height above the water in the dish equal to the difference of the level in the two globes.

148. **Intermittent fountain.**—The *intermittent fountain* depends partly on the elastic force of the air and partly on the atmospheric pressure. It consists of a stoppered glass globe, *a* (fig. 131), provided with two or three capillary tubulures. A glass tube, *d*, open at both ends, reaches at one end to the upper part of the globe, *a*; the other end is fitted in a support, *c*, placed in the middle of the dish, *m*, which supports the whole apparatus. The support, *c*, is perforated with small holes, which allow air to pass into the tube just above a little aperture in the dish, *m*.

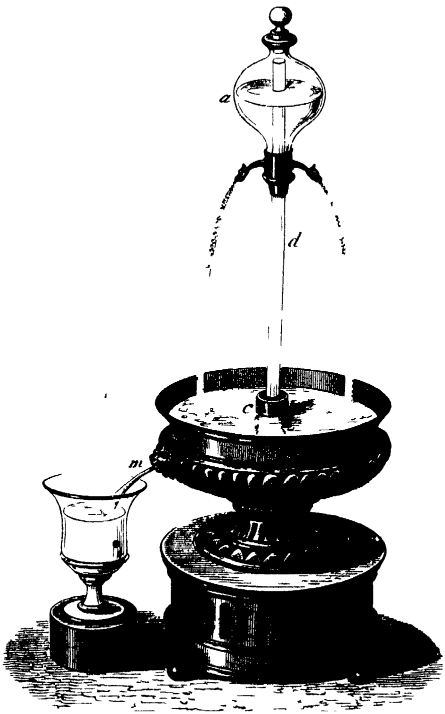


Fig. 131.

The water, with which the globe, *a*, is nearly two-thirds filled, runs out by the tubes, as shown in the figure; the internal pressure being equal to the atmospheric pressure, together with the weight of the column of water, while the external pressure at that point is only that of the atmosphere. These conditions prevail so long as the lower end of the glass tube is open, that is, so long as air can enter and keep the air in *a* at the same density as the external air; but the apparatus is arranged so that the orifice in the dish does not allow so much water to flow out as it receives from the upper tubes, in consequence of which the level gradually rises in the dish, and then closes the lower end

of the glass tube. As the external air cannot now enter the globe, *a*, the air becomes rarefied in proportion as the flow continues, until the pressure of the column of water, together with the elastic force of the air contained in the globe, is equal to this external pressure; the flow consequently stops. But as water continues to flow out of the dish at *m*, the tube opens again, air enters, and the flow recommences, and so on, as long as there is water in the globe *a*.

149. **Syphon inkstand.**—This vessel prevents ink from too rapid evaporation, and is an interesting illustration of the pressure of the atmosphere, and of the elasticity of air. It consists of a glass vessel of the shape of a truncated pyramid (fig. 132), closed everywhere except at the bottom, where there is a tubulure, which is always open. The inkstand is partially full of ink, while there is air at the top. The level of the ink inside being higher than in the tubulure, the elastic force of the air inside is a little less than the pressure of the atmosphere on the ink in the tubulure. As the ink there is used, its level sinks, and is finally lower than the point *o*. At this moment a bubble of air passes into the interior, and the elastic force being thereby increased, the level of the ink descends in the inside and rises in the tubulure. This goes on until the internal level is at the point *o*. More ink must then be added, which is effected by pouring it into the tubulure, care being taken to incline the inkstand in the opposite direction. The fountains in birdcages are on a similar principle.

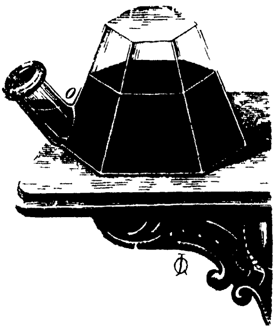


Fig. 132.

PUMPS.

150. **Suction pumps.**—Pumps are machines for raising liquids. Their invention, which is of great antiquity, is attributed to Ctesibius, a celebrated mechanician, who flourished at Alexandria, 130 B.C. They are met with in many modifications, but may all be referred to three types—*the suction or lift-pump*, *the forcing pump*, *and the suction and forcing pump*.

The suction or lifting pump, represented in fig. 133, consists of a cast-iron cylinder called the *barrel*, at the bottom of which is a

pipe of a smaller diameter, which dips in the well. At the top of this pipe is a clack valve, which is represented in the drawing as being open. It moves easily up and down, and it establishes a communication between the cylinder and the body of the pump when it is open, and breaks it when closed The piston in the

Fig 133

barrel consists of a thick disc of metal or of leather, coated with tow or with leather The piston is perforated by a small hole, which is closed by a valve, the valve is like that in the barrel, and, like it, opens upwards The piston is worked by means of a long lever, which is the *handle* This is joined at one end to a

forked rod, *a*, which is connected with the piston rod, *b*. As it is important that the piston move in a straight line, it is guided by passing through a hole in a fixed piece, *o*.

The manner in which the water is raised will be understood from an inspection of figs. 134, 135, and 136, which represent the piston and the valves in three different positions. When the pump has not been worked, the barrel and the pipe are full of air under the ordinary atmospheric pressure, which counterbalances the external atmospheric pressure on the well. Hence it follows

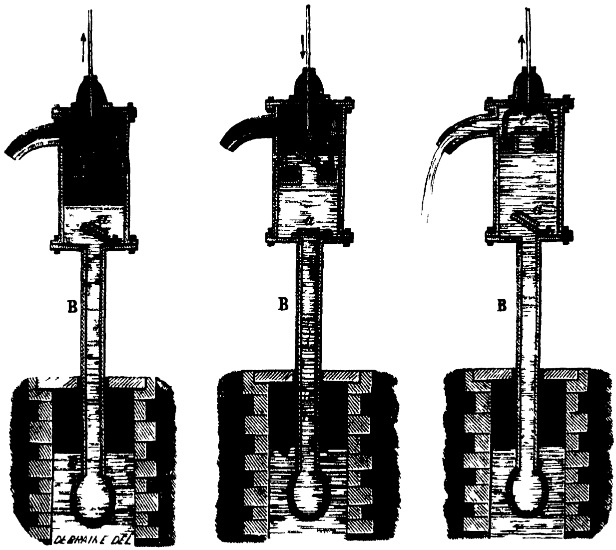


Fig. 134. Fig. 135 Fig. 136

that the level of the water inside and outside is the same. When the piston rises (fig. 134), since the valve *c* is pressed down by its own weight, and by that of the atmosphere, a vacuum is created below the piston; but, in virtue of its elastic force, the air which fills the pipe B soon opens the valve, *a*, and passes into the barrel. The air in the pipe B losing then in elastic force what it gains in volume (136), its pressure is no longer equal to the external pressure on the water in the well. Hence water rises in the pipe, as represented in the diagram. If now the piston sinks (fig. 135), the

valve *a* closes ; and as the air thus enclosed in the barrel becomes more and more compressed, a moment arrives when its elastic force exceeds the pressure of the atmosphere ; the valve *c* is then raised and air escapes into the top of the barrel, and thence into the atmosphere. With a second ascending stroke of the piston, the same phenomena are reproduced ; that is, the valve *c* falls and the valve *a* opens, the water, being thus raised in the pipe, ultimately passes beyond the valve *a*, and completely fills the barrel. From this time, when the piston re-descends, and the valve *a* closes, the pressure exerted on the water raises the valve *c*, and the water passes above the piston (fig. 135). Once this effect is produced, the valve *c* closes when the piston ascends, and the water which has passed above the piston, being raised with it, ultimately flows out by a spout in the side of the barrel.

Since it is the atmospheric pressure which raises the water in the pipe, the height of the valve *a*, above the level in the vessel, cannot exceed a certain limit. A column of water, 34 feet in height, balances, as we have seen, the pressure of the atmosphere (120). Hence if the pipe had a greater length than this, when once water had reached this height, the column of water in the pipe would balance the pressure of the atmosphere on the water of the well, and it could not be raised any higher. This, therefore, would be the extreme theoretical limit which the pipe could have ; but in practice the height of the tube A does not exceed 20 to 26 feet : for, although the atmospheric pressure can support a higher column, the vacuum produced in the barrel is never perfect, owing to the fact that the piston does not fit exactly on the bottom of the barrel. But when the water has passed the piston, it is the lifting force of the latter which raises it, and the height to which it can be brought depends on the force which works the piston.

151. **Force-pump.**—In this form of pump, water is not raised by the pressure of the atmosphere, but by the pressure of the piston on the water during its descent. For this purpose the piston is solid, that is, has no valve, and there is no lifting pipe, the barrel being immersed in the liquid to be raised (figs. 137 and 138). There are two valves in the barrel : one, *a*, in the bottom, opens upwards ; the other, *c*, is placed in the orifice of a long tube in the side of the pump.

When the piston rises (fig. 137), a vacuum being produced below it, the atmospheric pressure acts on *c*, and closes it ; while the water in which the pump is immersed, being forced by its own weight and

that of the atmosphere, raises the valve *a*, and passes into the barrel, which it fills completely. The motion of the valve is just reversed when the piston descends (fig. 138). By its own weight and by the pressure upon it, the valve *a* closes, while the valve *c* opens and gives exit to the water in the barrel, which then rises to a height depending on the pressure exerted by the piston. If this amounts to a pressure of one atmosphere, water rises 34 feet in the pipe H (120) ; if it is two atmospheres, water rises to 68 feet, and so on ; that is, always to a height of 34 feet for a pressure

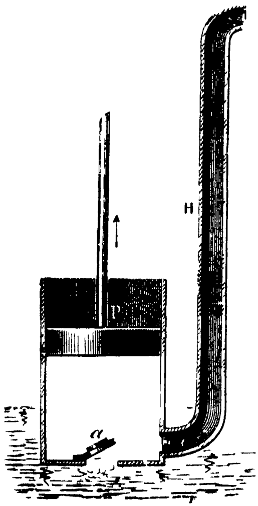


Fig. 137

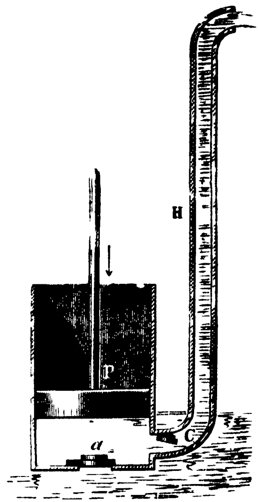


Fig. 138

of one atmosphere. The height, therefore, to which water can be raised in these pumps is not limited as it is in the suction-pump.

It will seen, from what has been said, that water only rises in the pipe H when the piston descends ; there is, therefore, an intermittent flow at the end of the pipe. A more regular flow is obtained by arranging two pumps, both forcing water into the same pipe, and in such a manner that when one piston rises the other sinks. It is by means of such an arrangement of two pumps that oil is raised to the wicks in Carcel's lamp. At the base of these lamps, and immersed in the oil itself, are two small pumps

worked by a clock-work motion, which is wound up like a clock. Such a system is also applied in fire-engines.

152. **Fire-engine.**—In a *fire-engine*, water has to be forced to a great height in a continuous stream. Fig. 139 represents a section of such a pump. Two rods which work the pistons *m* and *n* in two brass barrels, are fixed by means of joints to the handle PQ. Two pumps are placed in a trough, MN, of the same metal, which is called the *tank*, and which is fed with water while the pump is at work. Between these two is an air-chamber R, with a lateral

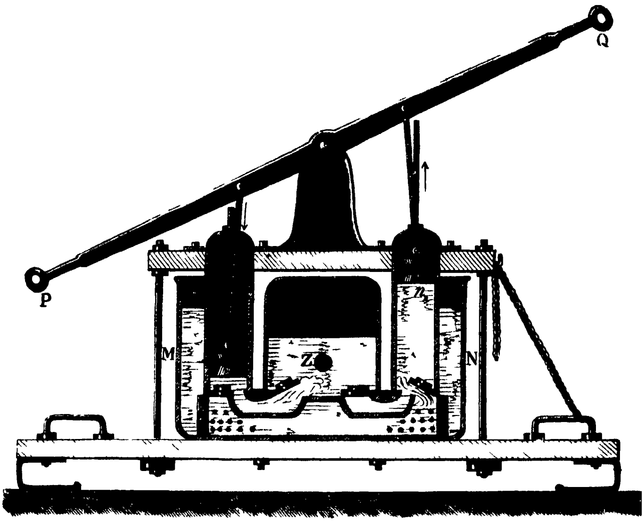


Fig 139

aperture Z, to which can be attached a long leather tube. This tube is provided at the end with a long conical copper tube, and which has an aperture only about three-fifths of an inch in diameter.

The use of the air-chamber is as follows: Although the pistons work alternately, there would necessarily be some intermittence in the jet when they are at the top or at the bottom of their course. But the water, instead of being forced by the pumps directly into the ascending pipe, first passes into the reservoir R, as shown in fig. 139. Owing to the resistance in the tube and on the jet, it flows out of the reservoir more slowly than it enters. Its level rises

in the reservoir, and, as the air is thereby reduced in volume, its pressure increases, so that the compressed air, reacting on the water when the pistons stop, forces out the water and thus keeps up the continuity of the jet. A good fire-engine worked by eight men will raise water to a height of 100 feet.

153. **The syphon.**—The syphon is a bent tube open at both ends and with legs of unequal length (fig. 140). It is used in transferring liquids, especially in cases in which they are to be removed without disturbing any sediment they contain. It is worked in the following manner : The syphon is filled with some liquid, and, the two ends being closed, the shorter leg is dipped in the liquid as

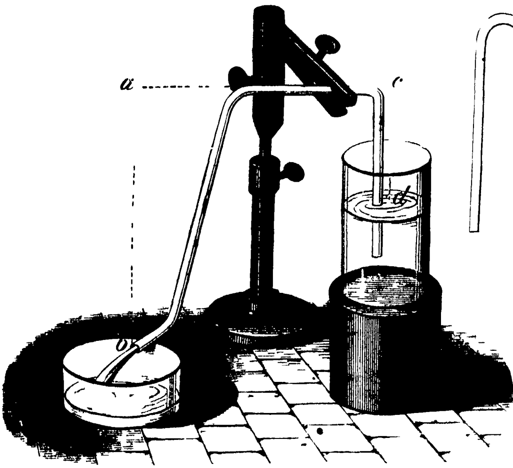


Fig. 140.

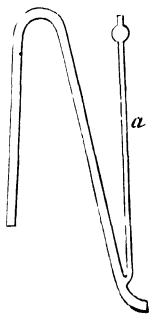


Fig. 141.

represented in fig. 140 ; or, the shorter leg having been dipped in the liquid, the air is exhausted by applying the mouth at *b*. A vacuum is thus produced, the liquid in *d* rises and fills the tube in consequence of the pressure of the air. It will then run out through the syphon as long as the shorter end dips in the liquid.

A syphon of the form represented in fig. 141 is used where the presence of the liquid in the mouth would be objectionable. A tube, *a*, is attached to the longer branch, and it is filled by closing the end of the longer limb, and sucking at the end of *a*.

To explain this flow of water from the syphon. let us suppose it filled and the short leg immersed in the liquid. The pressure then

acting on *d*, and tending to raise the liquid in the tube, is the atmospheric pressure less the height of the column of liquid, *cd*. In like manner, the pressure on the end of the tube *b* is the weight of the atmosphere less the pressure of the column of liquid, *ab*. But as this latter column is longer than *cd*, the force acting at *b* is less than the force acting at *d*, and consequently a flow takes place proportional to the difference between these two forces. The flow will therefore be more rapid in proportion as the difference of level between the aperture *b* and the surface of the liquid in *d* is greater.

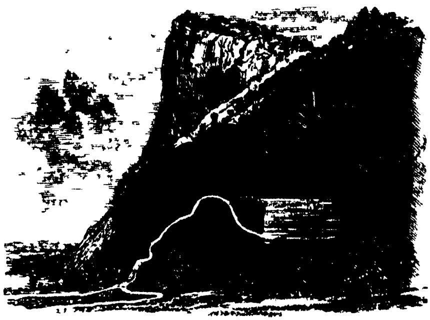


Fig 142

154. **Intermittent springs. Tantalus' cup.**—In nature, springs are met with whose flow is spontaneously interrupted, and which begins again after a longer or shorter interval. This phenomenon depends on the action of the syphon, and is readily understood by reference to fig. 142, which represents a subterranean reservoir fed by a series of fissures in the earth ; the channel by which the water flows out is on the left of the figure, and on coming to the surface it forms a spring. In the figure the reservoir is represented as just being filled, and when the water rises to the height of the bend the syphon begins to act. If the fissures by which water is supplied furnish a smaller quantity than that by which it flows out, the reservoir together with the channel is gradually emptied, and the flow then ceases. The reservoir gradually fills again, but the water cannot flow out until it has risen to the height represented by the dotted line, and the syphon has begun to work again.

Fig. 143

The action of Tantalus' cup, which is represented in fig. 143, will be at once understood ; and the same principle is applied in an arrangement frequently used by photographers for washing prints.

CHAPTER IV.

PRESSURE ON BODIES IN AIR. BALLOONS.

155. **Archimedes' principle applied to gases.**—The pressure exerted by gases on bodies immersed in them is transmitted equally in all directions, as has been shown by the experiment with the Magdeburg hemispheres. It therefore follows, that all which has been said about the equilibrium of bodies in liquids applies to bodies in air; they lose a part of their weight equal to that of the air which they displace.

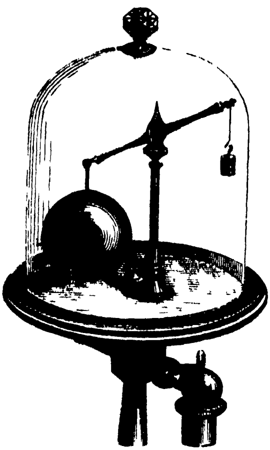


Fig. 144.

This loss of weight in air is demonstrated by means of the *baroscope*, which consists of a scale-beam, at one of whose ends a small leaden weight is supported, and at the other there is a hollow copper sphere (fig. 144). They are so constructed that in air they exactly balance one another, but when they are placed under the receiver of the air-pump and a vacuum is produced, the sphere sinks; thereby showing that in reality it is heavier than the small leaden weight. Before the air is exhausted each body is buoyed up by the weight of the air which it displaces. But as the sphere is much the larger of the two, its weight undergoes most apparent diminution; and thus, though in reality the heavier body, it is balanced by the small leaden weight. It may be proved by means of the same apparatus that this loss is equal to the weight of the displaced air, and we may thus generalise Archimedes' principle and say that any body plunged in any fluid, whether it be a liquid or a gas, loses part of its weight equal to the weight of the displaced fluid. Hence bodies weighed in air usually indicate too small a weight. To have an exact weight the volume

of the weights and of the displaced fluid should be exactly the same, which is seldom the case. The true weight of bodies is obtained by weighing them in a vacuum.

The principle of Archimedes being thus true for bodies in air, all that has been said about bodies immersed in liquids applies to them: that is, that when a body is heavier than air it will sink, owing to the excess of its weight over the buoyancy. If it is as heavy as air, its weight will exactly counterbalance the buoyancy, and the body will float in the atmosphere. If the body is lighter than air, the buoyancy of the air will prevail, and the body will rise in the atmosphere until it reaches a layer of the same density as its own. The force of the ascent is equal to the excess of the buoyancy over the weight of the body. This is the reason why smoke, vapours, clouds, and air balloons rise in the air.

156. **Air balloons.**—*Air balloons* are hollow spheres made of some light impermeable material, which, when filled with heated air, with hydrogen gas, or with coal gas, rise in the air in virtue of their relative lightness.

They were invented by the brothers Montgolfier, of Annonay, and the first experiment was made at that place in June 1783. Their balloon was a sphere of 40 yards in circumference, and weighed 500 pounds. At the lower part there was an aperture, and a sort of boat was suspended, in which was burnt paper and straw. The heated air thus produced gradually inflated the balloon, and when it was full of expanded air, which was thus lighter than the external air, the weight of the balloon and its hot air being less than that of the air which it displaced, it soon rose to a height of more than 2,000 yards, to the great astonishment of the assembled spectators. It rapidly descended, however, for the hot air it contained soon became cooled in the higher regions of the atmosphere.

The experiment at Annonay excited great interest all over France, and, pending the repetition on a larger scale at the expense of the Government, Charles, a professor of physics, constructed a smaller balloon, about 13 feet in diameter, which was filled with hydrogen instead of heated air. The use of hydrogen is very advantageous, for, as it is almost 14 times less dense than air, its ascensional force is far greater than that of hot air, and it is also less dangerous, for in heating the air there is a great risk of setting fire to the balloon. Charles made an ascent in 1783 in a balloon inflated by hydrogen.

Since then, the art of ballooning has been greatly extended, and many ascents have been made. That which Gay-Lussac made in

1804 was the most remarkable for the facts with which it has enriched science, and for the height which he attained—23,000 feet above the sea-level. At this height the barometer stood at 12·6 inches, and the thermometer, which was 31° C. on the ground, was 9 degrees below zero.

In these high regions, the dryness was such, on the day of Gay-Lussac's ascent, that hygrometric substances, such as paper, parchment, etc., became dried and crumpled as if they had been placed near the fire. The respiration and circulation of the blood were accelerated in consequence of the great rarefaction of the air. Gay-Lussac's pulse made 120 pulsations in a minute, instead of 66, the normal number. At this great height the sky had a very dark blue tint, and an absolute silence prevailed.

One of the most remarkable ascents was made by Mr. Glaisher and Mr. Coxwell in a large balloon belonging to the latter. This was filled with 90,000 cubic feet of coal gas (sp. gr. 0·37 to 0·33); the weight of the load was 600 pounds. The ascent took place at 1 P.M. on September 5, 1861; at twenty-eight minutes past 1 they had reached a height of 15,750 feet, and in eleven minutes afterwards a height of 21,000 feet, the temperature being −10·4°; at ten minutes to 2 they were at 26,200 feet, with the thermometer at −15·2°. At eight minutes to 2 the height attained was 29,000 feet, and the temperature −19·0° C. At this height the rarefaction of the air was so great and the cold so intense that Mr. Glaisher fainted, and could no longer observe. According to an approximate estimation the lowest barometric height they attained was 7 inches, which would correspond to a height of 36,000 to 37,000 feet.

157. **Construction and management of balloons.**—A balloon (fig. 145) is made of long bands of silk sewed together and covered with caoutchouc varnish, which renders it air-tight. At the top there is a safety-valve closed by a spring, which the aëronaut can open at pleasure by means of a cord. A light wicker-work boat is suspended by means of cords to a network which entirely covers the balloon.

A balloon of the ordinary dimensions, which can carry three persons, is about 16 yards high, 12 yards in diameter, and its volume when it is quite full is about 680 cubic yards. The balloon itself weighs 200 pounds; the accessories, such as rope and boat, 100 pounds.

The balloon is filled either with hydrogen or with coal gas.

Although the latter is heavier than the former, it is generally preferred, because it is cheaper and more easily obtained. It is passed into the balloon from the gas reservoir by means of a flexible pipe (fig. 145). It is important not to fill the balloon quite full, for the atmospheric pressure diminishes as it rises, and the gas inside,

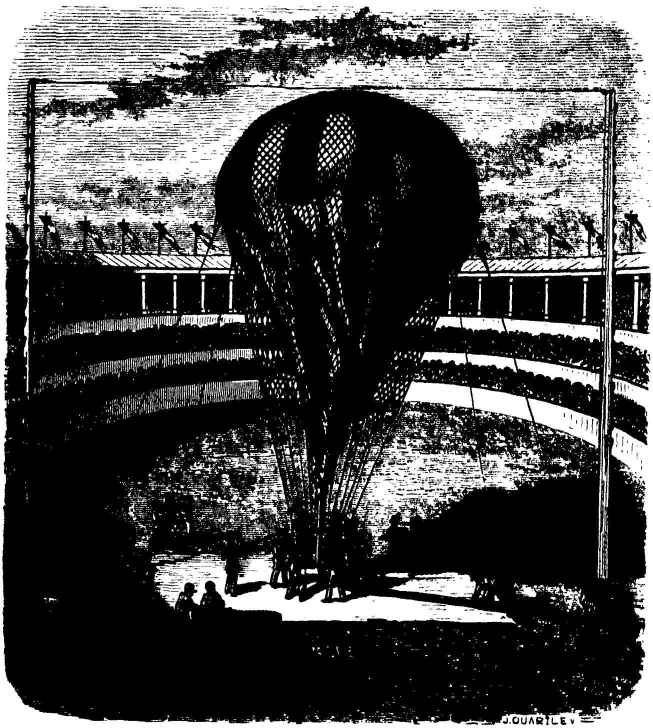


Fig. 145.

expanding in consequence of its elastic force, would tend to burst it. It is sufficient for the ascent if the weight of the displaced air exceeds that of the balloon by 8 or 10 pounds. The buoyancy due to this excess of weight is constant so long as the balloon is not quite distended by the expansion of the air in the interior. If the atmospheric pressure, for example, has diminished to one-half, the

gas in the balloon, according to Boyle's law, has doubled its volume. The volume of the air displaced is therefore twice as great; but since its density has become only one-half, the weight, and consequently the upward buoyancy, are the same. When once the balloon is completely dilated, if it continue to rise, the force of the ascent decreases, for the volume of the displaced air remains the same, but its density diminishes, and a time arrives at which the buoyancy is only equal to the weight of the balloon. The balloon can now only take a horizontal direction carried by the currents of air which prevail in the atmosphere. The aëronaut knows by the barometer whether he is ascending or descending; and by the same means he determines the height which he has reached. A long flag fixed to the boat would indicate by the position it takes, either above or below, whether the balloon is descending or ascending.

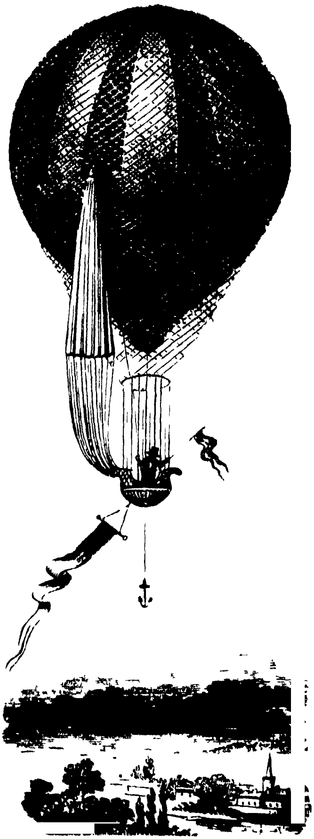


Fig 140

When the aëronaut wishes to descend, he opens the valve at the top of the balloon by means of the cord, which allows gas to escape, and the balloon sinks. If he wants to descend more slowly, or to rise again, he empties out bags of sand, of which there is an ample supply in the car. The descent is facilitated by means of a grappling iron fixed to the boat. When once this is fixed to any obstacle, the balloon is lowered by pulling the cord.

The only practical applications which air balloons have hitherto had have been in military reconnoitring. At the battle of Fleurus,

in 1794, a *captive* balloon—that is, one fastened to the ground by a rope—was used in which there was an observer, who reported the movements of the enemy by means of signals. At the battle of Solferino, the movements and dispositions of the Austrian troops were watched by a captive balloon; and in the war in America balloons were frequently used; while the part which they played in the siege of Paris is still fresh in all memories. Many ascents were made by Mr. Glaisher for the purpose of making meteorological observations in the higher regions of the atmosphere (156). Air balloons can only be truly useful when they can be guided, and as yet all attempts made with this view have completely failed. There is no other course at present than to rise in the air, until there is a current which has more or less the desired direction.

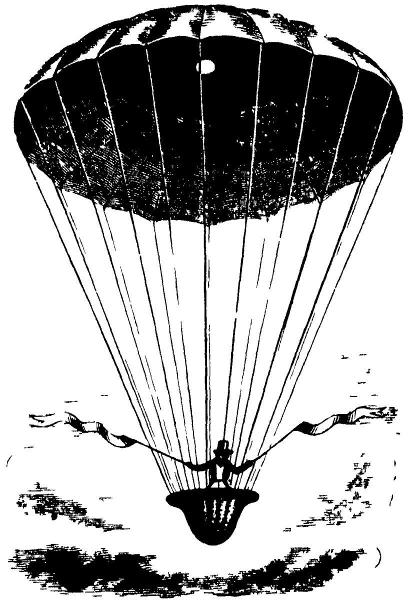


Fig. 147.

158. **Parachute.** — The object of the parachute is to allow an aëronaut to leave the balloon, by giving him the means of lessening the rapidity of his descent. It consists of a large circular piece of cloth (fig. 147) about 16 feet in diameter, and which by the resistance of the air spreads out like a gigantic umbrella. In the centre there is an aperture, through which the air, compressed by the rapidity of the descent, makes its escape; for otherwise oscillations might be produced, which, when communicated to the boat, would be dangerous.

In fig. 146 there is a parachute attached to the network of the balloon by means of a cord, which passes round a pulley, and is fixed at the other end to the boat. When the cord is cut, the para-

chute sinks, at first very rapidly, but more slowly as it becomes distended, as represented in the figure.

159. **Bellows.**—Fig. 148 represents a simple form of bellows, the action of which depends on the compression of air. Between two round wooden boards provided with handles, one of which has a valve, *k*, while the other works on a hinge, a folded leather bag

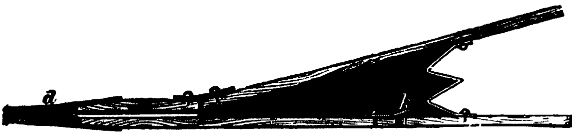


Fig 148.

is fastened. The inner space terminates in front in a short iron or brass pipe, *d*, which is called the *nozzle*. If now the upper lid is raised, the valve is opened, and air enters until the space is quite filled. When the handle is depressed the valve closes, the air is compressed, and forced out through the nozzle. Thus this arrangement, like that of the force pump, produces an intermittent flow of air.

BOOK IV.

ON SOUND.

CHAPTER I.

PRODUCTION, PROPAGATION, AND REFLECTION OF SOUND.

160. **Acoustics.**—This term is given to the scientific study of sounds, and of the vibrations of elastic bodies.

Music considers sounds with reference to the pleasurable feelings which they are calculated to excite in us. *Acoustics*, or the scientific study of sound, is concerned with the questions of the production, transmission, and comparison of sounds ; to which may be added the physiological question of the perception of sounds.

Sound is a peculiar sensation excited in the organ of hearing by the vibratory motion of bodies, when this motion is transmitted to the ear through an elastic medium.

Take, for instance, the string of a musical instrument, when it is pulled or sounded by a bow (fig. 149). When this is pulled aside

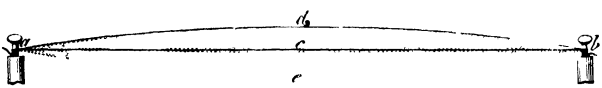


Fig. 149

from the position *acb*, where it is at rest, to the position *adb*, all the points being more or less out of their position of equilibrium, when the string is left to itself it tends to revert to its original position *acb*, owing to its elasticity. In virtue, however, of its acquired velocity, it passes beyond it as far as *aeb*, all the points being then virtually as far out of their position of rest as they were at *adb*. But as the elasticity still continues to act, not merely does the string revert to its original position, but it again passes beyond it and so

on, the amplitude of its path becoming smaller and smaller, as represented by the dotted lines in the figure, until it ultimately comes back to its original state of equilibrium. Hence each point of the string makes a backward and forward, or *vibratory* motion, like that of the pendulum. The passage from the position *adb* to *aeb*, and back to *adb*, is called a complete *vibration* or *oscillation*; the passage from *adb to aeb*, or from *aeb* to *adb*, is a *semi-vibration* or *semi-oscillation*.

Any body which vibrates or yields a sound is called a *sonorous* or *sounding* body. The vibrations of sounding bodies are generally too rapid to be directly counted or even distinctly seen. Yet they may be rendered evident in a variety of ways. Thus, if a tolerably large bell jar (fig. 150) be made to sound by striking it with the finger, and a small ivory ball, suspended by a thread, be approached to it, the ball will be observed to receive a series of rapid shocks from the sides of the bell, showing that it is in a state of vibration. Or if a plate of metal be fixed horizontally at one end, and sand be strewed over it, when the plate is made to vibrate by briskly moving a violin bow against the edge, the sand becomes violently agitated, which is obviously due to the vibrations of the plate.

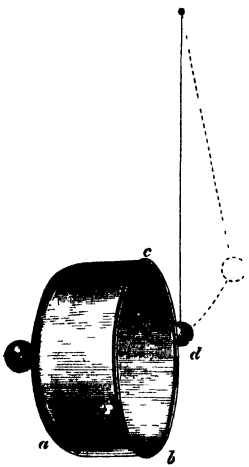


Fig. 150.

161. **Propagation of sound in the air. Sound waves.**—After having ascertained that when a body emits a sound, its molecules are in a state of vibration, it remains to explain how these vibrations are transmitted to the ear to produce the sensation of sound. Sound always requires for its transmission an elastic medium, which at one end is in contact with the sounding body, and at the other with the organ of hearing. Air is the ordinary medium through which sound is transmitted. As air is very mobile, compressible, and elastic, its molecules, being in contact with different points of the sounding body, acquire movements which are similar to those of these points; they go and come with these points, so that each molecule of air in contact with the body is pushed forward by it in the direction of the sound, and returns, having communicated its motion to the next molecule; this then acts in the same manner

on the next molecule, and so on to the molecules in contact with the *tympanum* or *drum* This is the name given to a membrane placed at the end of the auditory canal of the ear it receives the vibrations of the air, which it transmits by a series of small bones and liquids to the acoustic nerve, and thence to the brain, which finally perceives the sensation of sound

At each impulse imparted by a sounding body to the molecules of air in contact with it, these molecules pressing in turn upon the succeeding ones, a condensed part is produced in the air to a certain distance which is called the *condensed wave*, then, when the vibrating body reverts to its original position, the molecules nearest to it follow in its motion, so that there is formed in the air a rarefied

Fig 151

part which follows the condensed wave, and which is called the *rarefied wave* A condensed and rarefied wave together form a sound wave A sounding body is a centre from which these waves are emitted all round it in the form of continually increasing spheres, and thus it is that sound is propagated by a body in all directions Fig 151 furnishes a rough illustration of this progress If a stone is thrown into still water, there are formed round the point where it falls, a series of concentric waves, which continually increase, and which give an idea of the propagation of sound waves in the air

In the case of very loud sounds, the disturbance communicated to the air in the form of sound waves may be very considerable Thus the waves produced by thunder, by the report of cannon, and

ther under water, the shock is distinctly heard; and a diver at the bottom of the water can hear the sound of voices on the bank.

The conductibility of solids is such that the scratching of a pen at the end of a long wooden rod is heard at the other end. In like manner if a person whispers at the end of a long fir pole, he is heard by a person whose ear is applied against the other end, while a person who is near hears nothing. The earth conducts sound so well that at night, when the ear is applied to the ground, the galloping of horses, or any other noise at great distances, is heard.

An interesting example of the good conductivity of solids for sound is afforded by the *string telephone* (fig. 153). A piece of wet bladder, D, is tightly tied over a sort of flat wooden box, B, in the bottom of which is fitted a stout wooden tube, T, open at both ends, by which it can be fixed in a holder. A mouthpiece, M, is firmly fitted over the membrane, D; in the middle of this membrane a thin piece of ebonite is fixed by sealing wax, and to this a string, S, with a hook is attached. Two such apparatus are connected by tightly stretched string attached to the hook. If then one of the mouthpieces be spoken into, the membrane is set in vibration, and these vibrations are transmitted to the other membrane, which is also made to vibrate, so that a person holding his ear to the latter distinctly hears what is spoken even at a distance of some hundred yards.

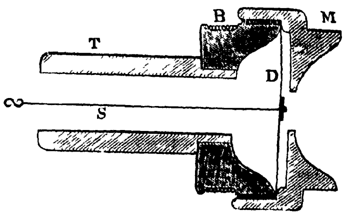


Fig. 153.

Wheatstone's 'invisible concert' was produced by means of four long rods of pine wood passed from the cellar of a house through the ceilings to an upper story. These were severally connected at the bottom with a piano, violin, violoncello, and clarionet, which being played produced in the upper room the curious effect of an invisible concert.

In mines the sound of the workman's blows is heard at great distances. Soldiers and hunters apply the ear to the ground to detect the distant steps of the enemy, or of game.

The fact that the firing of cannon can be heard at far greater

distances than thunder is no doubt due to the fact that the conductivity of the earth for sound is greater than that of air.

165. **Velocity of sound in air.**—Numerous phenomena show that sound requires a certain time to pass from one place to another. Thus, if we pay attention to a woodman felling trees at a distance, we see the axe fall in silence, and only hear the sound a moment afterwards. It looks, indeed, as if the sound were due to the tearing away of the axe from the tree. In like manner, when a gun is fired, the report is heard after the flash of light. Thunder, too, is only heard some time after lightning, although in the cloud both thunder and lightning are produced simultaneously.

The velocity of sound was determined experimentally by the members of the Bureau of Longitude of Paris in June 1822, during the night. A cannon was placed on a hill at Montlhéry near Paris, and another on a plateau near Villejuif. The distance of the two places was carefully measured, and was found to be 61,045 feet, and a gun was fired at each station twelve successive times at intervals of 10 minutes. By means of accurate and delicate watches, observers placed near the guns noted the time which elapsed between the appearance of the flash and that at which the sound was heard at the other station ; and the mean of the observations gave the number 54·6 seconds. This was just the time which the sound required to travel from one station to the other; for we shall afterwards see that the velocity of light is such that the time it requires to traverse the above distance is inappreciable. Hence by a simple calculation we find that sound travels 1,118 feet in a second.

The above observations were made when the air was at a temperature of 16°. At a lower temperature the velocity of sound is less.

From some accurate experiments made by the above method near Amsterdam, the velocity of sound is taken at 1,093 feet per second in dry air at zero. Its velocity increases about 2 feet per second for every degree Centigrade. So that at 15° C., which is the ordinary temperature, the velocity of sound is about 1,120 feet per second.

A knowledge of the velocity of sound enables us to measure distances. Thus, suppose we want to know the distance at which a gun is fired, the report of which we only hear 15 seconds after seeing the flash. As sound travels at 1,120 feet in a second, it must traverse 16,800 feet in the time mentioned, and this would be the

distance at which the gun was fired. In the same manner we may calculate the depth of a well from the number of seconds which elapse between the moment at which a stone is allowed to fall into it and that at which the sound is heard. The calculation is, however, more complicated, for the time which the body requires in falling has to be taken into account.

Knowing also the time that elapses between observing a flash of lightning and hearing the thunder, we can determine the distance at which the discharge takes place.

An instructive illustration of the time required for the transmission of sound may be observed when a long column of soldiers begins to march, to the beat of drummers placed at the head. A wave-like motion, which begins with the drummers, is seen to pass along the whole line. This is owing to the fact that all the soldiers do not begin the new step at exactly the same instant ; those that are behind hear the beat of the drums later than the front ones.

The velocity of sound is not the same in different gases ; it is greater in those which are less dense. Dulong found the velocity at zero to be 846 feet per second for carbonic acid, 1,040 feet in oxygen, and 1,093 in air, 1,106 in carbonic oxide, and 4,163 feet in hydrogen.

The velocity of sound is the same in air for all sounds, whether strong or weak, grave or acute. For this reason the tune played by a band is heard at a great distance without alteration, except in intensity, which could not be the case if some sounds travelled more rapidly than others.

166. **Velocity of sounds in liquids and in solids.**—We have already seen that liquids conduct sound ; they even conduct it better than gases. The velocity of sound in water was investigated in 1827 by Colladon and Sturm. They moored two boats (fig. 154) at a known distance in the Lake of Geneva. The first supported a bell, C, immersed in water, and a bent lever provided at one end with a hammer, *b*, which struck the bell, and at the other with a lighted wick, *e*, so arranged that it ignited some powder, *m*, the moment the hammer struck the bell. To the second boat was affixed an ear-trumpet, the bell, *gtk*, of which was in water, while the mouth *o* was applied to the ear of the observer, so that he could measure the time between the flash of light and the arrival of sound by the water. By this method the velocity was found to be 4,708 feet in a second at the temperature 8°, or four times as great as in air.

That sound travels more rapidly in solids than in air is easily shown. If a person holds his ear against one end of a tolerably long iron bar, while another person gives a hard blow at the other

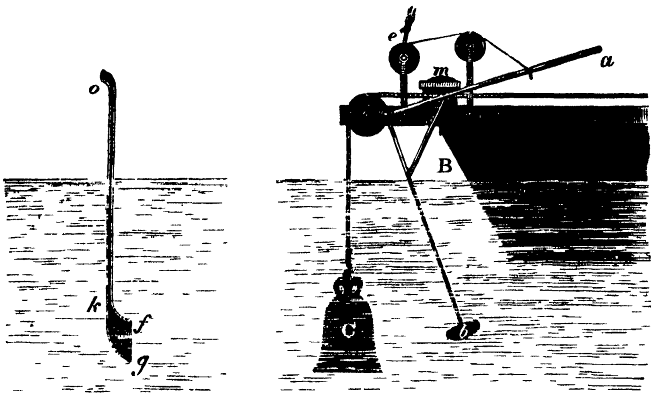


Fig. 154.

end, two distinct sounds are heard; the first transmitted by the metal, and the other transmitted by the air. The velocity of sound in iron is 16,800 feet in a second; in copper, 11,600; in oak, 10,900; and in pine, 15,220 feet.

167. **Reflection of sound.**—We have seen that sound is propagated in air by means of spherical waves, alternately condensed and rarefied, and which are developed about it in all directions. So long as these sound waves are not obstructed in their motion, they are propagated in the form of concentric spheres; but when they meet with an obstacle, they follow the general law of elastic bodies: that is, they are repelled like an ivory ball, which strikes against a wall; they return upon themselves, forming new concentric waves, which seem to emanate from a second centre on the other side of the obstacle. The phenomenon constitutes the *reflection of sound.*

The reflection of sound, or rather of sound waves, follows the same laws as the reflection of heat and of light, which we shall afterwards have to explain.

The reflection of sound may be demonstrated by means of the arrangement represented in fig. 155, which consists of two parabolic

mirrors placed at some distance opposite each other. At a certain position in front of one of them, called the *focus*, is placed a watch or other convenient sounding body. It is a property of this position, the focus, that all sound waves starting from it which fall on the adjacent mirror are thrown back in parallel rays. If these

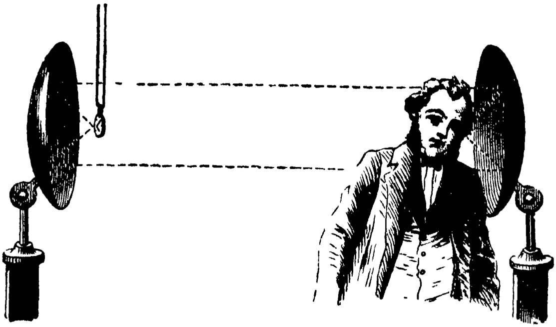


Fig. 155.

parallel rays fall on the second mirror, they are reflected to *its* focus, so that if the ear be placed there, the sound waves are concentrated in the ear, and the ticking of the watch is distinctly heard, which is not the case if the ear is in a different position. The hollow of the hand held behind the ear helps to concentrate sound, as may be seen in almost any ordinary assembly of listeners. The smooth surface of water powerfully reflects sound ; the barking of a dog or the ordinary street cries have been heard at a distance of some miles across a still lake.

As the laws of the reflection of sound are the same as those of light and heat, curved surfaces of natural occurrence often produce *acoustic foci*, like the luminous and calorific foci produced by mirrors. If a person standing under the arch of a bridge speaks with his face turned towards one of the piers, the sound is reproduced near the other pier with such distinctness that a conversation can be kept up in a low tone which is not heard by any one standing in the intermediate spaces.

There is a square room with an elliptical ceiling, on the ground floor of the Conservatoire des Arts et Métiers, in Paris, which presents this phenomenon in a remarkable degree, when persons stand in the two foci of the ellipse. So also bellying sails such as those

in fig. 15 are often found to act like mirrors (fig. 155) in concentrating sound from a distance in a focus.

Whispering galleries are formed of smooth walls, having a continuous curved form. The mouth of the speaker is presented at one point, and the ear of the hearer at another and distant point. In this case, the sound is successively reflected from one point to another until it reaches the ear. In a large circular room in London, the Colosseum, Wheatstone observed that a single exclamation was like a peal of laughter, and tearing a piece of paper sounded like the patter of hail. The Ear of Dionysius, in the quarries of Syracuse, concentrates the waves of sound similarly in one point.

It is not merely by solid surfaces, such as walls, rocks, etc., that sound is reflected, but whenever a sound wave passes from a medium of one density into another it undergoes partial reflection. In some cases this is strong enough to form an echo, and it always distinctly weakens the direct sound.

Different parts of the earth's surface are unequally heated by the sun, owing to the shade of trees, the evaporation of water, and other causes, so that in the atmosphere there are numerous ascending and descending currents of air of different densities. This produces, as Tyndall has observed and confirmed by experiments, a condition of the atmosphere which bears the same relation to sound that cloudiness does to light. The streams of air differently heated, or charged with aqueous vapour to varying extents, render the atmosphere, as it were, *flocculent* to sound. Air which is apparently quite transparent to light may, owing to the occurrence of what are in effect acoustic clouds, be more or less opaque to sound. Ordinary rain, snow, hail, and fog have no sensible effect in obstructing sound. In this we no doubt have the reason, as Humboldt remarks, why sound is heard farther at night than in the daytime; even in the South American forests, where the animals which appear silent by day fill the atmosphere in the night with thousands of confused sounds. To this may also be added that at night and in repose, when other senses are at rest, that of hearing becomes more acute.

168. **Echoes and resonance.**—An *echo* is the repetition of a sound in the air caused by its reflection from some more or less distant obstacle. Thus, if a few words are loudly spoken at a certain distance from a wood, a rock, or a building, it usually happens that, after a brief interval, the same phrase is heard repeated, as if spoken in the distance by another person; these are the sound

waves, which are reflected by the obstacle. There must, however, be a certain distance between the place at which the sound is produced and that at which it is heard.

A very sharp quick sound can produce an echo when the reflecting surface is 55 feet distant; but for articulate sounds at least double that distance is necessary, for it may be easily shown that no one can pronounce or hear distinctly more than five syllables in a second. Now, as the velocity of sound at ordinary temperatures may be taken at 1,120 feet in a second, in a fifth of that time sound would travel 224 feet. If the reflecting surface is 112 feet distant, sound would travel through 224 feet in going and returning. The time which elapses between the articulated and the reflected sound would therefore be the fifth of a second, the two sounds would not interfere, and the reflected sound would be distinctly heard. A person speaking with a loud voice in front of a reflecting surface at the distance of 112 feet can only distinguish the last reflected syllable: such an echo is said to be *monosyllabic*. If the reflector were at a distance of two or three times 112 feet, the echo would be *dissyllabic*, *trisyllabic*, and so on.

Multiple echoes are those which repeat the same sound several times; this is the case when two opposite surfaces (for example, two parallel walls) successively reflect sound. There are echoes which repeat the same sound 20 or 30 times. An echo in the château of Simonetta in Italy repeats a sound 30 times. At Woodstock there is one which repeats from 17 to 20 syllables. Near Verdun is an echo formed by two parallel towers, at a distance from each other of about 164 feet. A person placing himself between them, and speaking a word with a loud voice, hears it repeated a dozen times. Echoes usually modify sound; some repeat it with noise; others with a mocking, laughing tone or a plaintive accent.

We have seen that when the distance at which a sound is reflected is 112 feet, an echo is produced; and the question may be asked, What happens when the distance is less than this? As the sound has then a smaller distance to traverse, both in going and coming, than 112 feet, it follows that the reflected sound is added to the directly spoken one. They cannot be heard separately, but the sound is strengthened. This is what is often called *resonance*, and its effects are so much the more marked the more elastic are the surfaces from which the sound is reflected. In racket courts and in uninhabited houses, where there is no furniture, the

walls, the flooring, and the ceiling readily vibrate, and we all know how the noise of footsteps and the sound of the voice then resound. Tapestry and hangings, which are not elastic, *deaden* the sound.

The presence of an audience in an enclosed space may also render intelligible speech possible where without an audience the distinctness of the direct voice is destroyed by its echoes.

169. **Causes which influence the intensity of sound.**—Many causes modify the strength or the *intensity* of sound. These are, the distance of the sounding body, the amplitude of the vibrations, the density of the air at the place where the sound is produced, the direction of the currents of air, and, lastly, the neighbourhood of other bodies which can enter into a state of vibration.

i. *The intensity of sound is inversely as the square of the distance of the sounding body from the ear.* This law has been deduced by calculation, but it may be also demonstrated experimentally. Let us suppose several sounds of equal intensity, for instance, bells of the same kind, struck by hammers of the same weight, falling from equal heights. If four of these bells are placed at a distance of 20 yards from the ear, and one at a distance of 10 yards, it is found that the single bell produces a sound of the same intensity as the four bells struck simultaneously. Consequently, for double the distance, the intensity of the sound is only one-fourth.

The distance at which sounds can be heard depends on their loudness. The report of a volcano at St. Vincent was heard at Demerara, 300 miles off, and the firing at the battle of Waterloo was heard at Dover.

ii. *The intensity of the sound increases with the amplitude of the vibrations of the sounding body.* The connection between the intensity of the sound and the amplitude of the vibrations is readily observed by means of vibrating cords. For if the cords are somewhat long, the oscillations are perceptible to the eye, and it is seen that the sound is feebler in proportion as the amplitude of the oscillations decreases.

For the same reason the dying sounds of the last blows of a bell become gradually feebler, until they are ultimately extinguished.

iii. *The intensity of sound depends on the density of the air in the place in which it is produced.* As we have already seen (163), when an alarum moved by clockwork is placed under the bell-jar of the air-pump, the sound becomes weaker in proportion as the air is rarefied.

In hydrogen, which has about $\frac{1}{14}$th the density of air, sounds are much feebler, although the pressure is the same. In carbonic acid, on the contrary, which is half as heavy again as air, sounds are louder. On very high mountains, where the air is much rarefied, it is necessary to speak with some effort in order to be heard, and the discharge of a gun produces only a feeble sound. During a frost, sounds are heard at a greater distance, because air is then more dense and usually more homogeneous; and country people will thus often predict the weather from observing the sound of the village bell. For the propagation of sound is modified, as we have seen, by the occurrence of layers of air of different density.

iv. *The intensity of sound is modified by the motion of the atmosphere and the direction of the wind.* In calm weather sound is always better propagated than when there is wind; in the latter case, for an equal distance, sound is louder in the direction of the wind than in the contrary direction.

v. Lastly, *sound is strengthened by the neighbourhood of a sounding body.* A string made to vibrate in free air, and not near a sounding body, has but a very feeble sound; but when it vibrates above a sounding-box, as in the case of the violin, the guitar, the violoncello, or the pianoforte, its sound is much stronger. This arises from the fact that the box, and the air which it contains, vibrate in unison with the string. Hence the use of sounding-boxes in these instruments.

170. **Influence of tubes on the transmission of sound.**—The diminution in the intensity of sound with the distance is due to the fact that the sound waves are propagated in the form of continually increasing spheres; and it may indeed be proved geometrically that, since sound is thus transmitted, its intensity must be inversely as the square of the distance. If, however, the sound is sent through a long tube, the waves are propagated in only one direction, and sound can be transmitted to great distances without appreciable alteration. Biot found that in one of the Paris water-pipes, 1,040 yards long, the voice lost so little of its intensity that a conversation could be kept up at the ends of the tube in a very low tone; so much so that, in order not to be heard, it was necessary, as Biot expressed it, *not to speak at all.* The weakening of sound becomes, however, perceptible in tubes of large diameter, or where the sides are rough.

In Carisbrooke Castle in the Isle of Wight here is a well lined

with smooth masonry 212 feet deep and 12 feet wide; when a pin is dropped into the well it is distinctly heard to strike against the water; shouting and coughing into this well produces a resonant ring of some duration.

This property of transmitting sounds was first applied in England for *speaking-tubes*, which are used in mines, in hotels and large establishments, for transmitting orders. They consist of caoutchouc or metal tubes of small diameter, provided at each end with an ivory or bone mouthpiece, and passing from one room to another. If a person speaks at one end of the tube (fig. 156), he is distinctly heard

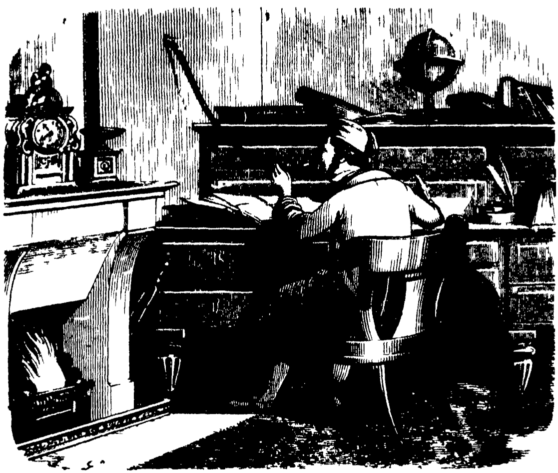
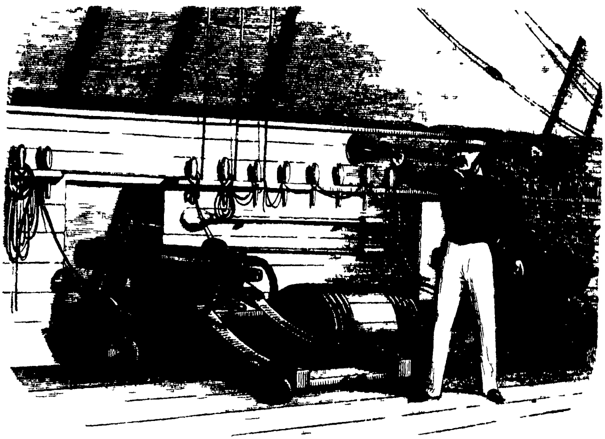


Fig. 156.

by a person applying his ear at the other end. Usually the main part of the tube is of zinc, and the part to which the mouthpiece is attached of caoutchouc.

One of the most important applications of acoustical principles is that of the *stethoscope*. It consists of a cylinder of hard wood about a foot long and 1¼ inch broad at one end, and in which a longitudinal passage is bored. One end of the stethoscope is held against the diseased part of the body, and the ear is held against the other. The practised physician can detect the existence of internal cavities by the peculiar sound emitted, and which is strengthened by resonance.

171. **Speaking-trumpets.**—The *speaking-trumpet*, as its name implies, is used to render the voice audible at great distances. It consists of of a slightly conical tin or brass tube (fig. 157) very much wider or funnel-shaped at one end (which is called the *bell*), and provided with a mouthpiece at the other. The larger the dimensions of this instrument, the greater is the distance at which the voice is heard. Its action is usually ascribed to the successive reflection of sound-waves from the sides of the tube, by which the waves tend more and more to pass in a direction parallel to the axis of the in-



strument. It has, however, been objected to this explanation, that the sounds emitted by the speaking-trumpet are not stronger solely in the direction of the axis, but in all directions ; that the bell would not tend to produce parallelism in the sound-wave, whereas it certainly exerts considerable influence in strengthening the sound. According to Hassenfratz, the bell acts by allowing a large mass of air to be set in consonant vibration before it begins to be diffused. By means of the speaking-trumpet, the word of command can be heard on board ship above the noise of the waves. The longer the trumpet the greater the distance to which sound is carried. A strong man's voice sent through a trumpet 20 feet in length has been heard at a distance of three miles.

172. **Ear-trumpet.**—The *ear-trumpet* is used by persons who

are hard of hearing. It is essentially an inverted speaking-trumpet, and consists of a conical metal tube, one of whose ends, terminating in a *bell*, receives the sound, while the other end is introduced into the ear (fig. 158). The action of this instrument is the reverse of that of the speaking-trumpet. The bell serves as mouthpiece; that is, it receives the sounds coming from the mouth of the person who speaks. These sounds are transmitted by a series of reflections to the interior of the trumpet, so that the waves, which would become greatly dispersed, are concentrated on the hearing

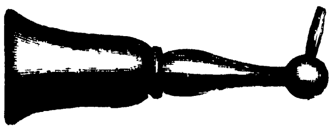


Fig. 158.

apparatus, and produce a far greater effect than divergent waves would have done.

In man and many animals the outer ear is a trumpet which receives the waves of sound. In some animals this part of the hearing apparatus is long and flexible, so that, by adjusting it, the animal can easily recognise the direction from which the sound proceeds. From this is no doubt derived the common phrase 'pricking up the ears.'

CHAPTER II.

MUSICAL SOUNDS. PHYSICAL THEORY OF MUSIC.

173. **Difference between musical sounds and noise.**—Sounds are distinguished from *noises*. Sound properly so called, or musical *sound*, is that which produces a continuous and regular sensation, and the rate of whose vibrations can be determined. The only condition necessary for producing a musical sound is that the individual impulses shall succeed each other with sufficient rapidity at equal intervals of time. Whatever be its origin, whether it be the ticks of a watch or the puffs of a locomotive, if this condition be fulfilled, the coalescence of the separate impressions produces a musical sound.

On the other hand, noise is either a sound of too short a duration to be determined, like the report of a cannon, or else it is a confused mixture of many discordant sounds, like the rolling of thunder, the rattling of a box of nails, or the noise of the waves. The difference between sound and noise is, however, by no means precise. Savart has shown that there are relations of height in the case of noise, as well as in that of sound, and there are said to be certain ears sufficiently well organised to determine the musical value of the sound produced by a carriage rolling over the square blocks of a granite pavement.

The action of a noise upon the ear has been compared to that of a flickering light upon the eye ; both are painful, in consequence of the sudden and abrupt changes which they produce in their respective nerves.

174. **Characteristics of musical sounds.**—Musical sounds or tones have three leading qualities, namely *pitch*, *intensity*, and *timbre* or *colour*.

i. The *pitch* or *height* of a musical tone is determined by the number of vibrations in a second yielded by the body producing the tone.

ii. The *intensity* or *loudness* of the tone depends on the *extent* of the vibrations. It is greater when the extent is greater, and less when it is less. It is, in fact, nearly or exactly proportional to the

square of the extent or amplitude of the vibrations which produce the tone.

iii. The *timbre* (the French word for 'stamp') is that peculiar quality of tone which distinguishes a note when sounded on one instrument from the same note when sounded on another. Thus when the C of the treble stave is sounded on a violin, and on a flute, the two notes will have the same pitch, that is, are produced by the same number of vibrations per second, and they may have the same intensity or loudness, and yet the two notes will have very distinct qualities—that is, their timbre is different (183). By some writers this peculiar property is called the *colour* of a sound.

175. **Syren.**—The vibrations of any sounding body are so rapid that they cannot be followed by the eye and counted. Various forms of apparatus have been invented for the purpose of determining the number of vibrations corresponding to particular notes. Of these, the one represented in fig. 159 is given as being the simplest and most intelligible. It consists of a circular disc of stout cardboard, or of sheet metal, about a foot in diameter. This disc is perforated by four concentric series of small equidistant holes. For simplicity's sake the inner of these is represented as having 12, the second 15, the third 18, and the fourth 24 holes; but a multiple of these ratios, say 48, 60, 72, and 96, is more convenient.

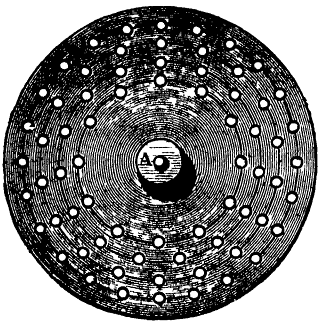


Fig. 159.

The disc is made to rotate rapidly, and the most convenient plan is to fix it on a turning table (fig. 16), in the place of AB. Then, by means of a glass tube, drawn out at one end so as to be smaller than the diameter of the holes, a current of air is directed against one of the series of holes in the rotating disc. A tone is now heard, which is tolerably pure when the rotations are sufficiently rapid, and the number of vibrations of which can be readily determined. Suppose, for instance, that there are 48 in the inner series of holes. Then each time a hole passes in front of the glass tube a condensed wave is produced which reaches the ear in the ordinary manner. If, for example, the disc makes

16 turns in a second, in each second, 16 times 48, or 768 holes, pass in front of the tube, and there are produced 768 waves, which fall npon the ear within a second, at equal intervals of time. If in like manner the tube were held over the second series of holes, while the rotation goes on at the same rate, we should hear the tones corresponding to 16 times 60, or 960 vibrations in a second. Thus proceeding in like manner, and moving the tube successively from the central to the circumferential series of holes, we hear successively the fundamental note, the major third, the fifth, and the octave (177).

176. **Limit of perceptible sounds.**—Savart, a French physicist, was the first to determine the limit of the number of vibrations which the ear could perceive. He invented an apparatus for this purpose which is known as *Savart's toothed wheel* (fig. 160). It

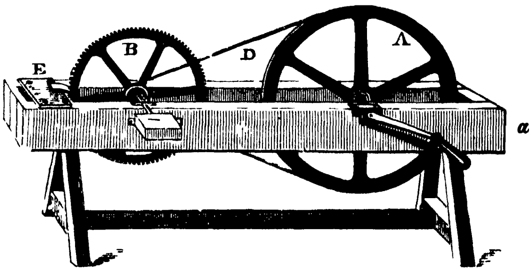


Fig. 160.

consists essentially of a metal wheel B, with a series of equidistant sharp teeth on its periphery. This is made to rotate at a uniform rate by the motion transmitted by a band, D, from a large wheel, A. and a card, or, still better, a thin elastic steel plate, E, is fixed so that, in the rotation of the wheel, each of the teeth strikes against the plate, and each time produces a sound. If, for instance, the rim of the wheel has 600 teeth, and it is made to rotate 4 times in a second, 2,400 impulses are given in a second. The number of impulses depends thus on the velocity of rotation, and the sounds produced are pure and continuous.

Thus, to determine the number of vibrations corresponding to any particular note, it is simply necessary to turn the wheel at a uniform rate until it produces a note in unison (178) with the one in question. Knowing then the number of teeth on the wheel and

the rate of rotation, which is ascertained by a clockwork motion on the side, the number of vibrations can be at once calculated. By means of this apparatus, Savart ascertained that the deepest sounds are produced by 16 vibrations in a second. If the number of vibrations is less, no continuous sound is heard. The same physicist found that the highest sound which the ear can perceive corresponds to 48,000 vibrations in a second. Between these two limits it will be seen what an enormous quantity of sounds may be produced and perceived. Yet the sounds used in music, and more especially in singing, are comprised within much narrower limits (181). Thus the number of vibrations produced by the human voice has been ascertained; and it has been found that the lowest notes of a man's voice are made by 190 vibrations in a second, and the highest notes by 678. The lowest note of a woman's voice corresponds to 572 vibrations, and the highest to 1,606.

177. **Musical scale. Gamut.**—The human ear can distinguish, not merely that which is the highest, or the lowest, among several sounds, but it can also appreciate the relations which exist between the numbers of vibrations corresponding to each of these sounds. Not, indeed, that we can say whether one sound produces two or three times as many vibrations as another; but whenever the number of vibrations of two successive or simultaneous sounds are in a simple ratio, these sounds excite in us an agreeable sensation, which varies with the ratio of the vibrations of the two sounds, and which the ear can readily estimate. Hence results a series of sounds characterised by relations, which have their origin in the nature of our organisation, and which constitute what is called the *musical scale.*

In this series the sounds are reproduced in the same order, in periods of seven, each period constituting the *diatonic scale* or *gamut*; and the seven sounds or *notes* of each gamut are designated by the names C, D, E, F. G, A, B, or by *ut* or *do*, *re*, *mi*, *fa*, *sol*, *la*, *si.* The first six of these letters are the first syllables of the lines of a hymn which was sung by the chorister children to St. John, their patron saint, when they prayed to be freed from hoarseness; and the word *si* is formed of the first letters of St. John's name.

Ut queant laxis **re**sonare fibris
Mira gestorum **fa**muli tuorum
Solve polluti **la**bii reatum
S ancte **I**oannes

The word gamut is derived from *gamma*, the third letter of the Greek alphabet, because Guido d'Arezzo, who first (in the eleventh century) represented notes by points placed on parallel lines, denoted these lines by letters, and chose the letter gamma to designate the first line.

If we agree to represent by 1 the number of vibrations of the fundamental note C or *do* of the gamut—that is to say, of the lowest note—experiment shows that the numbers of vibrations of the other notes of the scale are those given in this table :—

C	D	E	F	G	A	B	*c*
do	*re*	*mi*	*fa*	*sol*	*la*	*si*	*do*
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

This table does not give the absolute numbers of the vibrations of the various notes, but only their relative numbers. Knowing the absolute number of vibrations of the fundamental C, we may deduce those of the other notes by multiplying them by $\frac{9}{8}$, $\frac{5}{4}$, $\frac{4}{3}$ . . . or 2 respectively; and we thus find that at the octave (178) the number of vibrations is double that of the fundamental note.

The scale may be continued by taking the octaves of these notes, namely, *c*, *d*, *e*, *f*, *g*, *a*, *b*, and again the octaves of these last, and so forth.

178. **Intervals.**—An *interval* is the ratio of one sound to another; that is, the relation between the numbers of vibrations which produce these sounds.

The interval between any two consecutive notes of the gamut is called a *second*: such as the interval from *do* to *re*, from *re* to *mi*, from *mi* to *fa*, and so on.

If between any two notes which are compared there are one, two, three, four, five, or six intermediate notes, these intervals are called respectively a *third*, a *fourth*, *fifth*, *sixth*, *seventh*, and *octave*. These words are not used in the same sense as in fractional arithmetic; an interval of a fifth simply stands for the *difference* of pitch between the first and fifth notes of the scale. Thus the interval from C to E is a third, that from C to F a fourth, from C to G a fifth, from C to A a sixth, and from C to B a seventh, and from C to *c* an octave.

Although two or more notes may be separately musical, it does not follow that, when sounded together, they produce a pleasant sensation. When the ear can distinguish without fatigue the ratio between two sounds, which is the case when the ratio is simple, the

accord or co-existence of these two sounds forms a *consonance* ; but if the number of vibrations is in a complicated ratio, the ear is unpleasantly affected, and we have *dissonance.*

The simplest concord is *unison*, in which the numbers of vibrations are equal ; then comes the octave, in which the number of vibrations of one sound is double that of the other ; then the fifth, where the ratio of the sounds is as 3 to 2 ; the fourth, of which the ratio is 4 to 3 ; and lastly, the third, where the ratio is 5 to 4.

If three notes are sounded together they are concordant when the numbers of their vibrations are as 4 : 5 : 6. Three such notes form a *harmonic triad*, and if sounded with a fourth note which is the octave of the lowest, they constitute what is called a *major chord.* Thus C, E, G form a major triad, G, B, *d* form a major triad, and F, A, *c* form a major triad. C, G, and F have, for this reason, special names, being called respectively the *tonic*, *dominant*, and *sub-dominant*, and the three triads the *tonic*, *dominant*, and *sub-dominant* triads or chords respectively.

If, however, the ratio of any three notes is as 10 : 12 : 15, the three sounds are slightly disssonant, but not so much as to prevent them from producing a pleasant sensation. When these three notes, and the octave to the lower note, are sounded together, they constitute a *minor chord.*

The intervals between the notes in the scale are—

C to D $\frac{9}{8}$.	G to A $\frac{10}{9}$.
D to E $\frac{10}{9}$.	A to B $\frac{9}{8}$.
E to F $\frac{16}{15}$.	B to C $\frac{16}{15}$.
F to G $\frac{9}{8}$.	

It will be seen that there are here three kinds of intervals : the interval $\frac{9}{8}$ is called a *major tone*, and that of $\frac{10}{9}$ a *minor tone* ; the relation between the major and the minor tone is $\frac{9}{8} : \frac{10}{9} = \frac{81}{80}$, and is called a *comma.* The interval $\frac{16}{15}$ is called a *major semitone.* The major scale is formed of the following succession of intervals : a major tone, a minor tone, a major semitone, a major tone, a minor tone, a major tone, and a major semitone. It is this succession which constitutes the scale : the key note, or the tonic, may have any number of vibrations ; but, once its height is fixed, that of the other notes is always in the above ratio.

179. **On semitones and on scales with different key notes.**— It is found convenient for the purpose of music to introduce notes intermediate to the seven notes of the gamut ; this is done by

increasing or diminishing those notes by an interval of $\frac{25}{24}$, which is called a *minor semitone.* When a note (say C) is increased by this interval, it is said to be sharpened, and is denoted by the symbol C♯, called 'C sharp'; that is, the ratio of C♯ to C is as 25 : 24. When it is decreased by the same interval, it is said to be flattened, and is represented thus—B♭, called 'B flat'; that is, the ratio of B to B♭ is as 25 : 24. If the effect of this be examined, it will be found that the number of notes in the scale from C up to *c* has been increased from seven to twenty-one notes, all of which can be easily distinguished by the ear. Thus, reckoning C to equal 1, we have—

C	C♯	D♭	D	D♯	E♭	E	etc.
1	$\frac{25}{24}$	$\frac{27}{25}$	$\frac{9}{8}$	$\frac{75}{64}$	$\frac{6}{5}$	$\frac{5}{4}$	etc.

Hitherto the note C has been taken as the tonic or *key note.* Any other of the twenty-one distinct notes above mentioned, for instance G, or F, or C♯, etc., may be made the key note, and a scale of notes constructed with reference to it. This will be found to give rise in each case to a series of notes, some of which are identical with those contained in the series of which C is the key note, but most of them different. The same would be true for the minor scale as well as for the major scale, and indeed for other scales, which may be constructed by means of the fundamental triad.

180. **On musical temperament.**—The number of notes that arise from the construction of the scales described in the last article is enormous; so much so as to prove quite unmanageable in the practice of music, and particularly for music designed for instruments with fixed notes, such as the pianoforte or harp. Accordingly it becomes practically important to reduce the number of notes, which is done by slightly altering their just proportions. This process is called *temperament.* By tempering the notes, however, more or less dissonance is introduced, and accordingly several different systems of temperament have been devised for rendering this dissonance as slight as possible. The system usually adopted is called the system of *equal temperament.* It consists in the substitution between C and *c* of eleven notes at equal intervals, each interval being the twelfth root of 2, or 1·05946. By this means the distinction between the semitones is abolished, so that, for example, C♯ and D♭ become the same note. The scale of twelve notes thus formed is called the *chromatic scale.* It of course follows that the major triad becomes slightly dissonant. Thus in

the diatonic scale, if we reckon C to be 1, E is denoted by 1·25000, and G by 1·50000. On the system of equal temperament, if C is denoted by 1, E is denoted by 1·25992 and G by 1·49831.

With instruments such as the violin or violoncello it is possible to obtain all the intervals with perfect accuracy—that is, to obtain just temperament; this is also the case with the voice, where singers have been trained to sing without the accompaniment of a piano; hence it is here that we meet with the highest musical effect.

181. **The number of vibrations producing each note. The tuning-fork.**—Hitherto we have not assigned any numerical value to that symbol the note C. In the theory of music it is common to assign 256 double vibrations to the middle C. This, however, is arbitrary; its justification is the facility with which this number may be subdivided. An instrument is in tune provided the intervals between the notes are correct, when C is yielded by any number of vibrations in a second which does not differ much from 256. Moreover, two instruments are in tune with one another, if, being separately in tune, they have any one note, for instance C, yielded by the same number of vibrations. Consequently, if two instruments have one note (say C) in common, they can then be brought into tune jointly, by having their remaining notes separately adjusted with reference to that fundamental note. A *tuning-fork* or *diapason* is an instrument yielding a constant sound, and is used as a standard for tuning musical instruments. It consists of an elastic steel rod, bent as represented in fig. 161. It is made to vibrate either by drawing a bow across the ends, as shown in the figure, or by striking one of the legs against a hard body, or by rapidly separating the two legs by means of a steel rod. The vibration produces a note which is always the same for the same tuning-fork.

The note is strengthened by fixing the tuning-fork on a box open at one end, called a *resonance box* (182).

It has been remarked for some years that not only has the pitch of the tuning-fork—that is, *concert pitch*—been getting higher in the larger theatres of Europe, but also that it is not the same in London, Paris, Vienna, Milan, etc. This is a source of great inconvenience both to composers and singers, and a commission was appointed to establish in France a tuning-fork of uniform pitch, and to prepare a standard which would serve as an invariable type. In accordance with the recommendations of that body, a *normal tuning-fork* has been established, which is compulsory on all musical estab-

lishments in France, and a standard has been deposited in the Conservatory of Music in Paris.

It makes 870 single or 435 double vibrations in a second, and

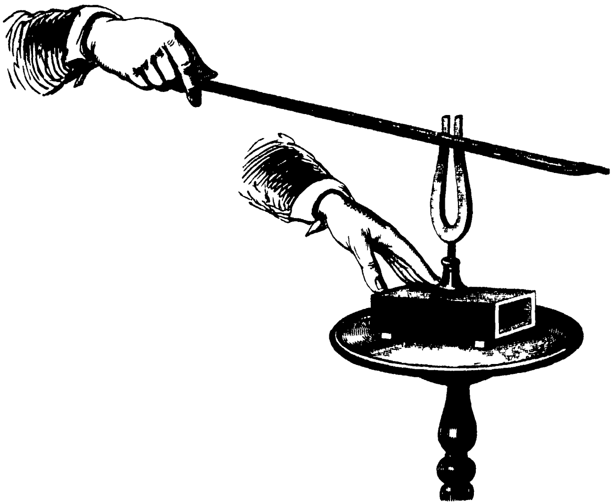
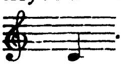


Fig. 161.

yields the note *la* of the treble stave; the *do* or C of the same stave makes thus 261 double vibrations in a second.

The standard tuning-fork adopted by the Society of Arts in London, on the recommendation of a committee of eminent musicians, makes 264 double vibrations in a second, and gives the middle C of the treble stave. The corresponding A or *la* gives therefore 440 vibrations in a second.

The middle C is the note sounded by the white key immediately on the left of the two black keys which are near the middle of the keyboard of a pianoforte. It is designated in musical notation as . For purposes of comparison it is convenient to call this note *c*′, and the next lower octave *c*; the octave lower than this C, and the still lower one $C_{,}$, and so on. The lowest note of grand pianos is $A_{,,}$, which gives 27·2 vibrations in a second.

In like manner the higher octaves are distinguished by affixes,

thus c'', c''', c^{v}, and so forth. In height the pianoforte reaches to a^{iv} with 3,520 or c^{v} with 4,422 vibrations in a second.

The practical range of musical sounds is comprised within 40 and about 4,000 vibrations in a second: or within a range of 7 octaves.

182. **Resonance of air.**—The action of the resonance-box in strengthening sound (fig. 161) may be illustrated by the following experiment (fig. 162). A B is a glass cylinder about 8 inches in height, and 1 to 1½ in diameter. If now an ordinary tuning-fork be made to vibrate, its sound is very faint, and if it is held over the empty cylinder probably no alteration will be experienced. When, however, water is slowly and noiselessly poured into the cylinder, on reaching a certain height the previously faint sound is far louder. Any other tuning-fork, which yields a different note, if held over the cylinder, will not have its note strengthened. Reverting now to the original tuning-fork, if, while it is still sounding and its sound is being strengthened by its nearness to the cylinder, we continue to pour in water, the sound becomes as faint as it was originally. If now the excess of water be again removed until the tone of the fork is once more strengthened, and if, removing the fork, we sound the column again by blowing into it, we find that the column of air emits the same note as the tuning-fork. Hence then the tuning-fork could set a column of air of a particular length in vibration so as to produce the same note; and this adding itself to the original note strengthened it.

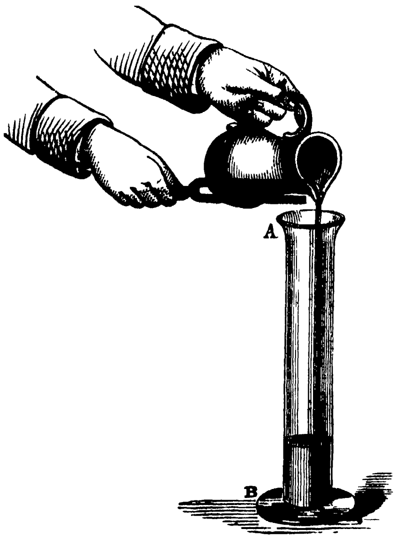


Fig. 162.

The rushing sound heard when certain large shells are held near the ear is caused by the fact that the mass of air in the shell responds to certain sounds and strengthens them.

183. **Compound musical notes. Harmonics. Overtones.**—We have already seen (174) that there is a peculiar quality or timbre, as it is called, by which the notes of different instruments are characterised. Thus we readily distinguish between the note C when sounded on a pianoforte and the same note sounded on an organ or a trumpet. This peculiarity of the tone is due to the fact that only in very few cases does an instrument give a pure note, but that in most cases it is accompanied by a series of upper notes or *harmonics*. To understand what these are we may refer to art. 195, in which it is stated that by successively intensifying the current of air we get in a stopped pipe a succession of notes the numbers of whose vibrations are as the series of odd numbers, 1, 3, 5, 7, etc. So, too, if we sound an open pipe in a similar way, we get the series of notes whose numbers of vibrations are represented by the series of numbers, 1, 2, 3, 4, 5, etc. These are called respectively the *odd* and *even harmonics* of the primary note.

Now, if we sound a particular note on the piano, a practised ear can discover, by a little attention, that the primary note is accompanied by a series of higher notes, each of which gradually gets fainter. These upper notes may be detected, and the compound nature of the primary sound analysed, even by an unpractised ear, by the use of *resonance globes* which Helmholtz devised for this purpose. These instruments, one of which is represented in fig. 163, are an application of the principle explained in the foregoing paragraph. They are small hollow spheres; the projection *b*, which has a small hole, is placed in the ear while the wider aperture *a* is directed towards the source of sound. Each of these resonators is constructed or tuned for a particular note; so that if, having sounded the string of a pianoforte, we hold near it a resonator tuned for a particular note, this note if present will be intensified. Thus, if we depress the key *c* we hear no particular strengthening if a resonator tuned for *g* be held near the ear; but when the resonators sounded for *c′*, *g′* *c″* are used we hear them powerfully respond when held to the ear. Hence the notes *c′*, *g′*, *c″* are contained in the mass of sound which is produced when the key *c* is depressed.

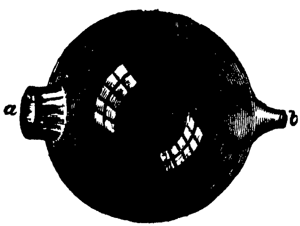


Fig. 163.

Helmholtz's researches show that the different timbre or quality of the sounds yielded by different instruments is due to the fact that they are accompanied in each case by special harmonics or *overtones* in varying intensity; some of his principal results are as follows:—

Simple notes—those, that is to say, without any admixture of overtones—are most easily produced when a tuning-fork is held near a resonance-box of suitable length. These notes are soft and are free from all sharpness and roughness.

The notes of the *flute* are also nearly pure, for their overtones are very feeble. Wide-stopped organ pipes give the fundamental note almost perfectly pure; narrower ones give along with it the fifth of the octave.

Wide open pipes give the octave along with the fundamental note; and narrower ones give a series of overtones.

The overtones present in the sound of stretched strings depend on their substance and on the manner in which they are made to sound. In good *pianos* the overtones are powerful up to the sixth. *In stringed instruments* the fundamental note is comparatively stronger than in pianos; the first overtones are feebler, the higher, from the sixth to the tenth, on the contrary, are far more distinct, and produce the penetrating character of the sound of stringed instruments. In the pianoforte (187) the place at which the string is struck is $\frac{1}{7}$ to $\frac{1}{9}$ of the whole length. It appears that this position gives rise to just those overtones which produce the most beautiful musical effect.

Metallic rods and *plates* produce, along with the fundamental note, a series of very high overtones which are discordant with each other, but are continuous and of equal strength with the primary note. Thus is produced that peculiarity known as a metallic sound.

By the occurrence of the lower harmonics along with the primary note the tone is more sonorous, richer and deeper than the primary note; by the occurrence of the higher overtones, the clang acquires its penetrating character.

CHAPTER III.

TRANSVERSE VIBRATIONS OF STRINGS. STRINGED INSTRUMENTS.

184. **Transverse vibrations of strings.**—We have already seen (160) that when an elastic string, stretched at the ends, is removed from its position of equilibrium, it reverts to it as soon as it is let go, making a series of vibrations which produce a sound. The strings used in music are commonly of catgut or metal wire. The vibrations which strings experience may be either *transverse* or *longitudinal*, but practically the former are alone important. *Transverse vibrations* may be produced by drawing a bow across the string, as in the case of the violin ; or by striking the string, as in the case of the pianoforte ; or by pulling them transversely and then letting them go suddenly, as in the case of the guitar and the harp.

185. **Laws of the transverse vibrations of strings.**—The number of transverse vibrations which a string can give in a certain time—that is, the sound it yields—varies with its length, its diameter, its tension, and with its specific gravity, in the following manner :—

The tension being constant, the number of vibrations in a second is inversely as the length ; that is, if a string makes 18 vibrations in a second, for instance, it will make 36 if its length is halved, 54 if its length is one-third, and so on. On this property depend the violin, the double bass, etc., for in these instruments, by pressing the string with a finger, the length is reduced or increased at pleasure, and the number of vibrations, and therewith the note, is regulated.

With strings of the same length and tension *the number of vibrations in a second is inversely as the diameter of the string ;* that is, the thinner a string, the greater its number of vibrations, and the higher its pitch. In the violin, the treble string, which is the thinnest, makes double the number of vibrations of that which would be made by a string the diameter of which is twice as great.

The number of vibrations in a second is directly as the square root of the stretching weight or tension; that is, when the tension of a string is four times as great, the number of vibrations is doubled; when the tension is nine times as great, the number is trebled, and so on. This, then, furnishes a means of altering the character of a note by stretching, as is done in stringed instruments.

Other things being equal, *the number of vibrations in a second of a string is inversely as the square root of its density.* Hence the greater the density of the material of which strings are made, the less easily they vibrate, and the deeper are the sounds they yield.

From the preceding laws it will be seen how easy it is to vary the number of the vibrations of strings and make them yield an extreme variety of sounds, from the deepest to the highest used in music.

186. **Verification of the laws of the vibrations of strings. Sonometer.**—This may be effected by means of an instrument

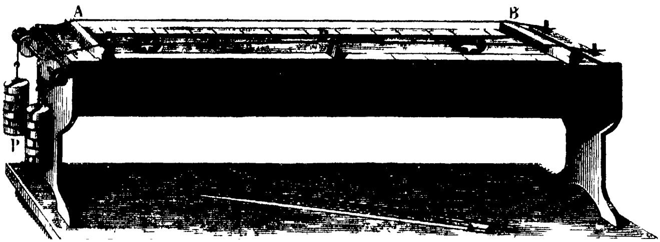


Fig 164.

called the *sonometer* or *monochord.* It consists of a thin wooden box to strengthen the sound. On this there are two fixed bridges, A and B (fig. 164), over which pass the strings AB, CD, which are commonly metal wires. These are fastened at one end, and stretched at the other by weights, P, which can be increased or diminished at will. By means of a third movable bridge, D, the length of that portion of the wire which is to be put in vibration can be altered at pleasure.

If two strings are taken which are identical in all respects, and are stretched by equal weights, they will be found, on being struck, to yield the same sound. If now one of them be divided by the movable bridge D into two equal parts, the sound yielded by CD will be the higher octave of that yielded by the entire string AB,

which shows that the number of vibrations is doubled, and thus verifies the law.

To verify the second law, the bridge D is removed. If the string AB is taken so that it has double the diameter of the other, but both are stretched by the same weight, it will be found that the sound which the thinnest string yields is the next higher octave of that yielded by AB; proving thus that the number of vibrations is doubled.

The two strings being of the same diameter, and the same length, if the weight which stretches the one be four times that which stretches the other, the sound yielded by the first is the higher octave of that of the second, which shows that the number of vibrations is doubled; when the weight is nine times as great, the sound is the higher octave of the fifth of the former.

The fourth law is established by using strings of different materials, copper, steel, catgut, and therefore of different densities, but of the same dimensions, and stretched to the same extent.

187. **Stringed instruments.**—Stringed musical instruments depend on the production of transverse vibrations. In some, such as the piano, the sounds are *constant*, and each note requires a separate string: in others, such as the violin and guitar, the sounds are *varied* by the fingering, and can be produced by fewer strings.

In the piano the vibrations of the strings are produced by the stroke of the *hammer*, which is moved by a series of bent levers communicating with the keys. The sound is strengthened by the vibrations of the air in the *sounding-box* on which the strings are stretched. Whenever a key is struck, a *damper* is raised, which falls when the finger is removed from the key and stops the vibrations of the corresponding string. By means of a *pedal* all the dampers can be raised simultaneously, and the vibrations then last for some time.

The harp is a sort of transition from the instruments with constant to those with variable sounds. Its strings correspond to the natural notes of the scale; by means of the pedals the lengths of the vibrating parts can be changed, so as to produce sharps and flats. The sound is strengthened by the sounding-box, and by the vibrations of all the strings harmonic with those played.

In the violin and guitar, each string can give a great number of sounds according to the length of the vibrating part, which is determined by the pressure of the fingers of the left hand while the right hand plays the bow, or the strings themselves. In both these instruments the vibrations are communicated to the upper face of

the sounding-box, by means of the bridge over which the strings pass. These vibrations are communicated from the upper to the lower face of the box, either by the sides, or by an intermediate piece called the *sound-post.* The air in the interior is set in vibration by both faces, and the strengthening of the sound is produced by all these simultaneous vibrations. The value of the instrument consists in the perfection with which all possible sounds are intensified, which depends essentially on the quality of the wood, and the relative arrangement of the parts.

Instruments of the class of the violin are very difficult to play, and require a very delicate ear; but in the hands of skilful artists they produce marvellous effects. They are the very soul of an orchestra, and the most beautiful pieces of music have been composed for them.

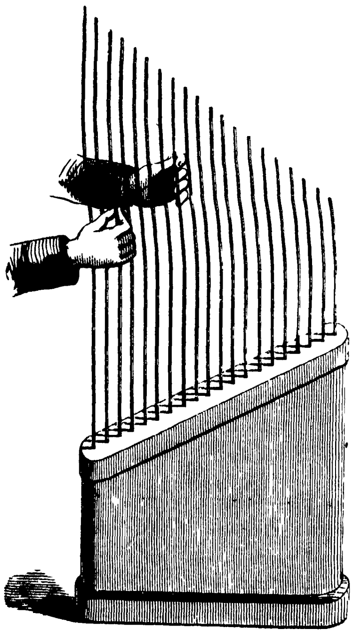


Fig. 165.

188. **Longitudinal vibrations of strings and rods.**—When a violin bow is passed over the string of the monochord at a very acute angle, an unpleasant but powerful tone is heard. If the tension of the string be altered, there is no change in the note. If the string be touched in the middle, it yields the octave when the bow is passed over it. These tones are produced by longitudinal vibrations; their pitch varies inversely as the length of the string, but is independent of the thickness and tension. In like manner, if a glass tube be grasped in the middle, and rubbed lengthwise with a wet cloth, a penetrating but not unpleasant tone is produced. If grasped at a quarter of its length, and if the shorter part be made to vibrate, the octave of the former tone is obtained.

Marloye's harp, fig. 165, is an arrangement which illustrates the sounds produced by the longitudinal vibration of rods. It consists

of a series of deal rods of different lengths and thicknesses. They are sounded by rubbing the rods lengthwise with resined fingers. A series of notes of varying pitch is thus produced, which by a skilful artist is far from unpleasing.

Another instrument of this kind is the *glass harmonicon.* This consists of plates of glass of the same breadth and thickness but of different lengths (fig. 166). They are fastened on two narrow ribbons, which are stretched in a converging direction on a suitable support, which is sometimes provided with a sound-board. If any of these plates are struck with a small wooden hammer, it gives a tone which is higher the shorter the plate.

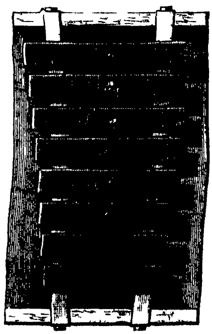


Fig. 166.

An instrument of this kind, with steel plates, is played by Papageno in the 'Zauberflöte.' If the strips of steel are replaced by strips of wood which are laid upon plaits of straw, we have what is known as the *straw fiddle.*

A similar arrangement of a number of pieces of flint of suitable sizes gives beautiful sounds when struck, and is known as the *geological piano.*

The *tuning-fork*, the *triangle*, and *musical-boxes* are examples of the transverse vibration of rods. In musical-boxes small plates of steel of different dimensions are fixed on a rod like the teeth of a comb. A cylinder whose axis is parallel to this rod, and whose surface is studded with steel teeth arranged in a certain order, is placed near the plates. By means of a clockwork motion the cylinder rotates, and the teeth striking the steel plates set them in vibration, producing a tune, which depends on the arrangement of the teeth on the cylinder.

189. **Chladni's Figures.**—The vibration of plates may be well illustrated by what are known as *Chladni's Figures.* A metal plate is clamped, as represented in figure 167, and a violin bow is passed smartly along the edge. By so doing higher or lower notes are produced corresponding to different periods of vibration of the plate. These vibrations are made apparent if the plate has been previously strewed with sand; the plate divides itself into vibratory segments, in which the vibration is at a maximum, separated from each other by nodal lines or places of no vibration. The sand dances off these segments and gradually settles on the lines, and

thus forms beautiful and characteristic figures. These vibrating parts are of less extent, and therefore the nodal lines more numerous, the higher the tones. Their arrangement and therewith the nature of the tones, depends with one and the same plate on the manner in which it is sounded by the bow, and also on the way in which it is damped. If a particular point of the plate is damped, a nodal line is produced passing through the given point, and, at the same time that a special system of nodal lines is formed, a new note results from the vibration. Figures 168 to 171 represent the figures produced when the plate is stroked with a bow in the part denoted by the letter *b*, while at the same time the plate is damped by the finger being held at *a*.

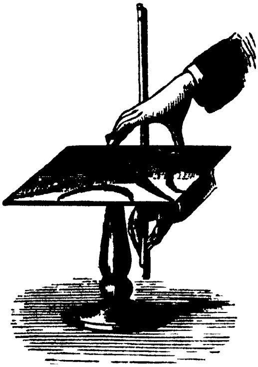


Fig. 167

Fig. 168.

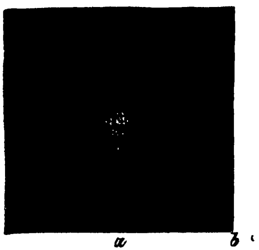


Fig. 169.

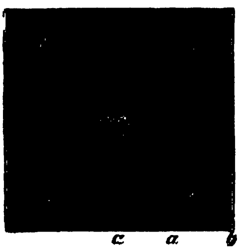


Fig. 170.

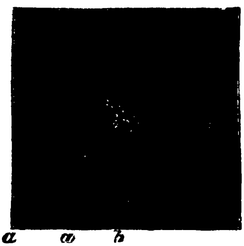


Fig. 171.

If the plate is damped elsewhere than in the centre, other and more complicated figures are produced.

CHAPTER IV.

SOUND PIPES AND WIND INSTRUMENTS.

190. **Production of sound in pipes.**—Sound pipes are hollow pipes or tubes in which sounds are produced by making the enclosed column of air vibrate. In the cases hitherto considered the sound results from the vibrations of solid bodies, and the air only serves as a vehicle for transmitting them. In wind instruments, on the contrary, when the sides of the tube are of adequate thickness, the enclosed column of air is the sounding body. In fact, the substance of the tubes is without influence on the primary tone; with equal dimensions it is the same whether the tubes are of glass, of wood, or of metal. These different materials do no more than give rise to different harmonics, and impart a different timbre to the compound tone produced.

If tubes were simply blown into, there could be no sound; there would merely be a continuous progressive motion of the air. To produce a sound, by some means or other a rapid succession of condensations and rarefactions must be produced, which are then transmitted to the whole column of air in the tube. Hence the necessity of having a *mouthpiece*—that is, the end by which air enters—so shaped that the air enters in an intermittent, and not a continuous, manner. From the arrangement made use of to set the enclosed air in vibration, wind instruments are divided into *mouth* instruments and *reed* instruments.

191. **Mouth instruments.**—In mouth instruments all parts of the mouthpiece are fixed. The pipes are either of wood or metal, rectangular or cylindrical, and are always long as compared with the diameter. Fig. 172 represents a wooden rectangular organ pipe; fig. 173 gives a longitudinal section by which the internal details are seen. The lower part, P, by which air enters, is called the *foot*; the air emerges through a narrow slit, *i*, and on the opposite side is a transverse aperture called the *mouth*; *a* and *b* are the *lips*, the upper one of which is bevelled.

The current of air, arriving by the mouth, strikes against the

upper lip, is compressed, and by its elasticity reacts upon the current and stops it. This, however, only lasts for an instant, for, as the air escapes at *ab*, the current from the foot continues, and so on for the whole time.

In this way pulsations are produced, which, transmitted to the air in the pipe, make it vibrate, and a sound is the result. In order that a pure note may be produced, there must be a certain relation

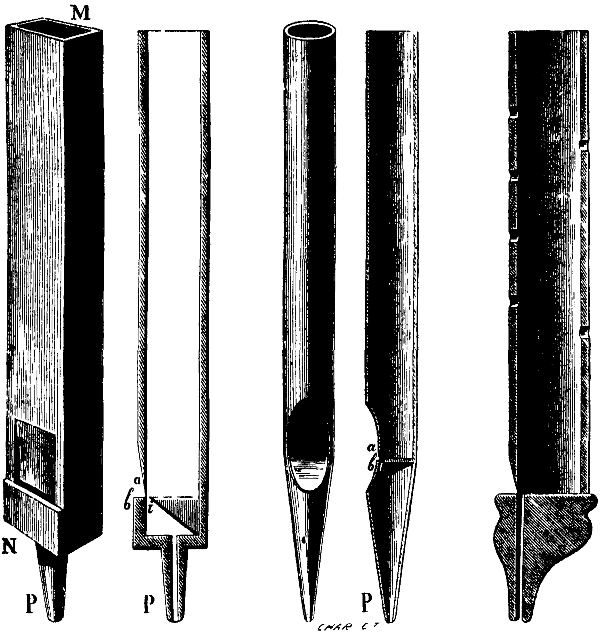


Fig 172 Fig. 173. Fig 174. Fig 175 Fig 176.

between the form of the lips and the magnitude of the mouth ; the tube also ought to have a great length in comparison with its diameter. The number of vibrations depends in general on the dimensions of the pipe, and the velocity of the current of air.

The mouthpiece we have described is used in organs. Fig. 174 represents another modification much in use in organ playing, and fig. 175 gives a longitudinal section. The letters indicate the same parts as in fig. 173. Fig. 176 shows the mouthpiece of a flageolet

and whistle. In the German flute the mouthpiece consists of a small lateral circular aperture in the pipe. By means of his lips the player causes the current of air to graze against the edge of this aperture.

192. **Reed instruments.**—In reed instruments the air is set in vibration by means of elastic tongues or plates, which are called *reeds*, and which are divided into free reeds and beating reeds.

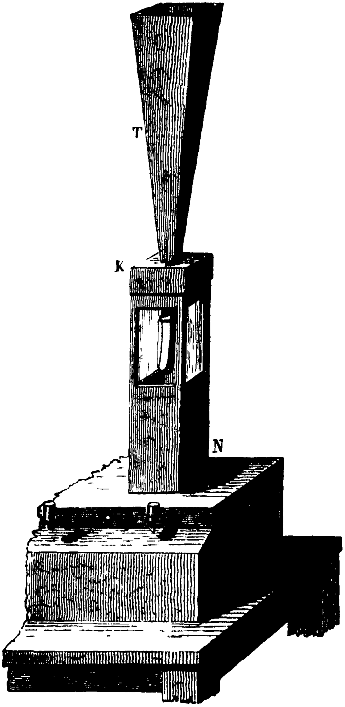


Fig. 177.

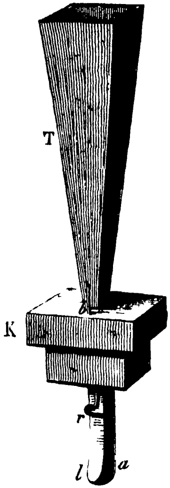


Fig. 178.

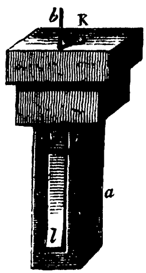


Fig. 179

Beating reed. This consists of a piece of wood or metal, *a* (fig. 178), which is grooved like a spoon. It is fixed to a kind of stopper, K, perforated by a hole, which connects the cavity with a long pipe, T. The groove is covered by a brass plate, *l*, which is called the *tongue*. In its ordinary position this is slightly away from the edges of the groove, but, being very flexible, readily

approaches, and closes it. Lastly, a curved wire, *br*, presses against the tongue, and can be moved up and down. The vibrating part of the tongue can thereby be shortened or lengthened at will, and the number of vibrations thus regulated. By means of this wire, reed pipes are tuned.

The reed is fitted to the top of a rectangular pipe KN, called the *wind channel.* This is closed everywhere, except at the bottom, where it can be fitted on a bellows. In models of reed pipes used in illustrating lectures, the sides of the upper part of the tube are made of glass, so as to show the construction of the reed. This arrangement is represented in fig. 177.

When air arrives in the wind channel, it first passes between the tongue and the groove, and escapes by the pipe T ; but, as the velocity increases, the tongue strikes against the edge of the groove, and, closing it completely, the current is stopped. But, in virtue of its elasticity, the tongue reverts to its original position, and thus, by a series of alternate openings and closings, the same series of pulsations is produced as in mouth instruments ; hence is formed a sound which is higher the more rapid the current of air.

Free reed. This is a kind of reed so called because the tongue, instead of striking against the edges of the groove, like the reed described above, grazes them so as to oscillate backwards and forwards. The groove consists, in this case, of a small wooden box, *ac*, fig. 179, the front of which is of brass plate. In the middle of this is a longitudinal slit, in which is applied the tongue, which can oscillate freely backwards and forwards so as to allow air to pass, which it closes each time it grazes the edges of the slit. In this case also a wire, *r*, regulates the length of the vibrating part of the tongue.

A reed can be very simply made from a piece of straw. About an inch from a knot an incision is made at *r* (fig. 180), with a sharp penknife, which is about a quarter as deep as the diameter

Fig. 180.

of the straw ; and then by laying the knife flat the straw is slit as far as the knot ; the strip *r r*, thus produced, forms a reed joined with the pipe *s r*. The note of this pipe depends on the length of the tube *s r*, and is higher the shorter the tube is made. In order to sound the pipe, the whole length of the reed is placed in the mouth and the lips firmly closed.

193. **Bellows.**—In acoustics a *bellows* is an apparatus by which wind instruments, such as the syren and organ pipes, are worked. Between the four legs of a table there is a pair of bellows, S (fig. 181), which is worked by means of a pedal, P. R is a reservoir of flexible leather, in which is stored the air forced in by the bellows. If this reservoir is pressed by means of weights on a rod, T, moved by the hand, the air is driven through a pipe, A, into a *wind chest*, *mn*, fixed on the table. In this chest there are small holes closed

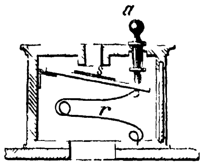


Fig 182

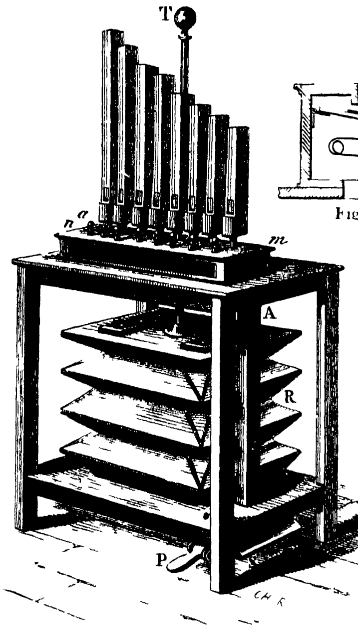


Fig 181

by leather valves, *s* (fig. 182). These can be opened by pressing on keys, *a*, in front of the box. Below the valve is a spring, *r*, which raises the valve when the key is not depressed. The sound pipe is placed in one of these holes.

194. **Nodes and loops.**—Experiment shows that when a pipe is sounded the column of air is subdivided into equal parts, vibrating in unison, and separated by surfaces where the velocity of air

is null. These fixed parts are called *nodes*; and the part between the nodes where the column of air is in a state of vibration is called a *loop*, or a *ventral* segment.

It will be seen afterwards that one and the same pipe may be made to yield several sounds, and that the nodes and ventral segments then alter their position. When a pipe closed at one end, *a stopped pipe*, is made to yield its fundamental sound—that is, the deepest sound—the bottom is always a node, and the mouthpiece a ventral segment. When an open pipe is sounded it has a ventral segment at each end; and, if it yields the fundamental sound, there is a single node in the middle.

When an aperture is opened in the side of a sounding pipe, the sound does not change if the aperture corresponds to a loop; but if it corresponds to a node, the sound is altered, for this node then becomes a loop. This property is used in wind instruments like the flute, or the clarionet, along which holes are made which can be closed by the fingers, or by the aid of keys.

The formation of nodes and loops in a sounding pipe may be

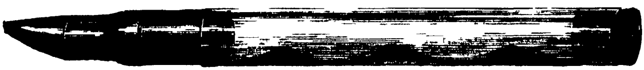


Fig. 183.

well illustrated by what are known as Kundt's *dust figures*. A simple modification of the experiment by Mayer is the following. A portion of a child's wooden whistle (fig. 183) is cut off just behind the first finger-hole, and cemented into a glass tube about three times its length. This tube is closed at the end with a cork and contains a quantity of powdered silica, or of very finely sifted sand. When the fundamental note of the pipe is sounded by blowing into it, the dust is set in vibration, forming a series of nodes and loops; the powder remains quiescent at the nodes, but accumulating on the ventral segments increases towards the centre.

195. **Laws of the vibration of air in pipes.**—The vibrations of air in pipes present two cases according as they are *open* or *stopped.*

Laws of stopped pipes. When, having placed a stopped pipe on the bellows, air is slowly passed, the deepest note, the fundamental sound, is produced. If, then, we denote by 1 the corresponding number of vibrations, when the current of air is forced, we suddenly

get the sound corresponding to 3; and if the wind be still more forced we have successively the sounds 5, 7, etc.: that is to say, sounds which by their pitch correspond to vibrations, 3, 5, 7, etc. times as numerous as those of the fundamental sound. Hence *when the air is forced closed pipes give successively sounds represented by the series of odd numbers.*

The sounds 3, 5, 7, etc. are called the *odd harmonics* of the fundamental note 1.

2. *With pipes of different lengths, the numbers of vibrations corresponding to the fundamental note are inversely as the lengths;* that is to say, a pipe which is half as long as another will yield a sound which is the octave of that yielded by this pipe.

Laws of open pipes. The fundamental note being still represented by unity, the harmonics obtained by forcing the wind are successively represented by 2, 3, 4, 5, 6, etc., that is, *by the natural series of numbers*, or the even harmonics.

The fundamental note of an open pipe is always an octave higher than the fundamental note of a closed pipe of the same length.

These laws are known as *Bernouilli's laws*, from the name of their discoverer, Daniel Bernouilli.

Fig. 184.

196. **Pitch pipe.**—Instead of using organ pipes of various lengths and bellows, these laws may be conveniently demonstrated by means of a *pitch* pipe, fig. 184, which is a small sound pipe with a movable graduated stopper. If, having closed the pipe at its full length, we blow into it, we get the fundamental note of the stopped pipe, say *c*; if now we blow into it more strongly we get the note *g'*, which is the major fifth of the higher octave of *c*; and more strongly still, the note *e''*, which is the major third of its second octave; and so on for the others.

In like manner having just closed the pipe, if we push in the stopper until its length is one half and sound it, we get the higher octave of the fundamental note; by making it $\frac{1}{8}$ its original length we get the major third of *c*; and so for any other aliquot part.

By removing the stopper altogether we have an open pipe, and the note *c'* which it yields is the octave of the stopped one, and this, sounded by increasingly powerful currents of air, gives the following series of notes, *c''*, *g''*, *c'''*, *e'''*, and so forth.

197 **Wind instruments.**—Wind instruments are straight or curved tubes, which are sounded by means of a current of air forced into them. They have all an aperture by which air is forced into them, and, according to the form of this aperture, they are divided into mouth instruments and reed instruments; in some, such as the organ, the notes are *fixed*, and require a separate pipe for each note; in others the notes are *variable*, and are produced by only one tube; the flute, horn, etc. are of this class.

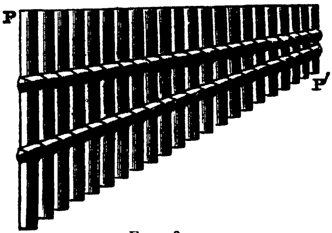


Fig. 185.

The Pan's pipe, the flageolet, and the German flute are mouth instruments. The principal reed instruments are the clarionet, the oboe, the cornopean, and the bassoon.

The *Pan's pipe*, fig. 185, consists of tubes of different sizes corresponding to the different notes of the gamut.

In the *organ* the pipes are of various kinds—namely, mouth pipes, open and stopped, and reed pipes with apertures of various shapes. The air is furnished by means of bellows, from which it passes into the wind chest, and thence into any pipe which is desired; this is effected by means of valves which are opened by depressing keys like those of the piano. In the larger and richer organs there are several rows of key-boards arranged at different heights.

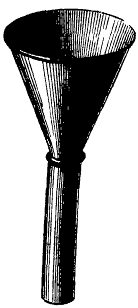


Fig. 186.

In the *flute*, the mouthpiece consists of a simple lateral circular aperture; the current of air is directed by means of the lips so that it grazes the edge of the aperture. The holes at different distances are closed either by the fingers or by keys; when one of the holes is opened, a loop is produced in the corresponding layer of air, which modifies the distribution of nodes and loops in the interior, and thus alters the note. The whistling of a key is similarly produced.

Mouth instruments. In the trumpet, the horn, the trombone, cornet-à-piston, and ophicleide, the lips form the reed, and vibrate in the mouthpiece (fig. 186), which terminates in a smaller tube by which it can be affixed to the instrument. In the *horn*, different

198. **The human voice.**—If we bevel off the ends of a piece of gutta-percha or of wooden tubing, so that two summits are left and if now two pieces of thin vulcanised india-rubber or leather be stretched and tied between them so as to leave a narrow slit, we have then a sort of membranous reed pipe (fig. 187). For if we blow into the tube we get a note which is higher the tighter the lips are stretched; and the vibrations of the lips which form the slit can be distinctly seen.

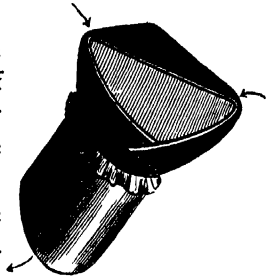


Fig. 187.

This simple experiment well illustrates the manner in which the sound of the human voice is produced.

The *trachea* or *windpipe* is a tube which terminates at one end in the lungs, and at the other in the *larynx*, which is the true organ of vocal sound. Fig. 188 represents a horizontal section of this organ. It consists of a number of cartilaginous structures, *bb*, which are connected by various muscles, by which great variety and control in the motions are attainable. These muscles are connected with, and move, two elastic membranes or bands with broad bases fixed to the larynx, and with sharp edges *cc*; these are called the *vocal chords*. According to the pressure of the muscles these chords are more or less tightly stretched, and the space between them, the *vocal slit*, is narrower or wider accordingly. In ordinary breathing, air passes through the triangular aperture *o*; but when in singing this is closed, the vocal chords are stretched,

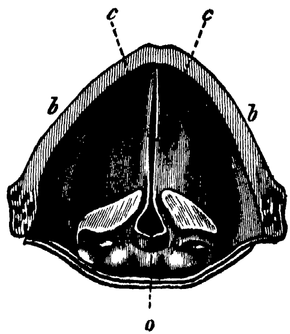


Fig. 188.

and are put in vibration by the current of air, and produce tones which are higher the more tightly the chords are stretched, and the narrower is the vocal slit. These changes can be effected with surprising rapidity, so that in this respect the human voice far exceeds anything that can be made artificially.

The notes produced by men are deeper than those of women or boys, because in them the larynx is longer and the vocal chords larger and thicker; hence, though equally elastic, they vibrate less swiftly. The vocal chords are 18 millimètres long in men, and 12 millimètres long in women. Chest notes are due to the fact that the whole membrane vibrates, while the falsetto is produced by a vibration of the extreme edges only. The ordinary compass of the individual voice is within two octaves, though this is exceeded by some celebrated singers.

The essential sonorous part of the human voice is formed by the *vowels.* They acquire their special sound by the fact that to produce them in each case the cavity of the mouth spontaneously alters its shape, and thus acts as a special resonator to each sound. The consonants are sounds which, formed by the lips, tongue, and teeth, accompany the vowels at their commencement and cessation.

The sounds by which the consonants are produced are much less intense than the vowel sounds. Hence they are inaudible at distances at which the vowel sounds can be distinctly heard. Therefore, in speaking with people hard of hearing, it is by no means necessary to speak louder, but it is sufficient to intensify the consonants. Indeed, distinctness of speech does not depend on loud screaming, but is produced by careful articulation.

BOOK V.

ON HEAT.

CHAPTER I.

GENERAL EFFECTS OF HEAT. THERMOMETERS.

199. **Heat. Hypothesis as to its nature.**—The sensations of heat and cold are familiar to all of us. In ordinary language the term *heat* is not only used to express a particular sensation, but also to describe that particular state or condition of matter which produces this sensation. Besides producing this sensation, heat acts variously upon bodies; it melts ice, boils water, makes metals red-hot, decomposes chemical compounds, and so forth.

Of the various theories as to the cause of heat, two only need be mentioned: these are the *theory of emission*, and the *theory of undulation.*

On the first view, heat is caused by a subtle imponderable fluid, which surrounds the molecules of bodies, and which can pass from one body to another. These *heat atmospheres*, which thus surround the molecules, exert a repelling influence on each other, in consequence of which heat acts in opposition to the force of cohesion. The entrance of this substance into our bodies produces the sensation of warmth: its egress, the sensation of cold.

On the second hypothesis the heat of a body is caused by an oscillating or vibratory motion of its material particles, and the hottest bodies are those in which the vibrations have the greatest velocity and the greatest amplitude. Hence, on this view, heat is not a *substance*, but a *condition of matter*, and a condition which can be transferred from one body to another. It is also assumed that there is an imponderable elastic ether, which pervades all bodies, the densest, or the most transparent solids or liquids, the most attenuated gases as well as the stellar spaces, and which is capable

of transmitting a vibratory motion with great velocity. A rapid vibratory motion of this ether produces heat, just as sound is produced by a vibratory motion of atmospheric air, and the transference of heat from one body to another is effected by the intervention of this ether.

This hypothesis is now admitted by the most distinguished physicists; it affords a better explanation of the phenomena of heat than any other theory, and it reveals an intimate connection between heat and light. In accordance with it, heat is a *form of motion*; and it can be shown that heat may be converted into motion, and, conversely, that motion may be converted into heat.

Although the undulatory theory of heat is the correct one—the one, that is, which best explains and accounts for the greatest number of facts—yet it may be sometimes convenient to use language which is based on the older hypothesis. Thus, in speaking of a body becoming heated or cooled, we say that it gains or loses heat; in reality, the vibratory motion of the particles is increased or diminished.

In what follows, however, the phenomena of heat will, as far as possible, be considered independently of either hypothesis.

200. **General effects of heat.**—The general effects of heat upon bodies is to increase the velocity of the vibratory motion of their molecules and accordingly to lessen molecular attraction (4). Under its influence, therefore, bodies tend to *expand*—that is, to assume a greater volume.

All bodies expand by the action of heat. As a general rule, gases are the most expansible, then liquids, and lastly, solids. The expansion of bodies by heat is thus a new general property to be added to those already studied (6).

The action of heat upon bodies is not merely to expand them; when raised to a certain point bodies first lose their solidity and become somewhat softer; then, as the heat still increases, the force of repulsion balances molecular attraction, and bodies liquefy. Wax, resin, sulphur thus pass readily from the solid to the liquid state; heat, therefore, produces in solids a change of state of aggregation. But in liquids it also produces a similar change. When bodies are heated they first expand; heated still more, their molecular attraction is again overcome by the force of repulsion, and bodies are then changed into aëriform liquids called vapours.

If, instead of becoming accumulated in bodies, heat is given out—that is, if bodies are cooled instead of being heated—the opposite

phenomena are produced : the molecules come nearer each other, the volume of the pores diminishes, and with it that of the body: which is expressed by saying that the body *contracts*. By cooling, vapours, losing their elastic force, revert to the liquid state ; and liquids themselves, by the same process, gradually return to the solid state. Thus water changes into ice, and mercury becomes as hard as lead.

Hence, according as heat increases in, or is lost by, bodies, two physical effects may be produced : 1. Changes in volume, consisting in expansions and contractions. 2. Changes of condition—that is, the change of solids into liquids, of liquids into vapours, and conversely. We shall first discuss the expansion of bodies, and afterwards their changes of state.

201. **Expansion.**—All bodies are expanded by heat, but to very

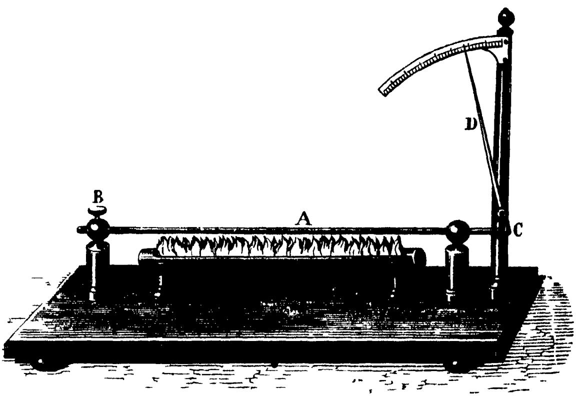


Fig. 189

different extents. Gases are most expansible, then liquids, and after them solids.

In solids, which have definite figures, we can either consider the expansion in one dimension, or the *linear* expansion ; in two dimensions, the *superficial* expansion ; or in three dimensions, the *cubical* expansion or the expansion of volume, although one of these never takes place without the other. As liquids and gases have no definite shapes, we can only consider the alterations of volume which they undergo.

To show the linear expansion of solids, the apparatus represented

in fig. 189 may be used. A metal rod, A, is fixed at one end by a screw, B, while the other end presses against the short arm, C, of an index, D, which moves on a scale. Below the rod, A, there is a sort of cylindrical lamp in which spirit is burned. The needle, D, is at first at the zero point, but, as the rod becomes heated, the needle moves along the scale, which shows that the short arm, C, of the lever is slightly displaced, pushed by the rod, A, as it expands.

It will be observed that, if rods of different metals are used, the index will be moved to different extents, showing that their expansibility differs. Thus it will be found that brass is more expansible than iron or steel.

The cubical expansion of solids may be shown by means of a *Gravesande's* ring. It consists of a brass ball *a* (fig. 190), which at the ordinary temperature passes freely through a ring *m*, of almost the same diameter. But when the ball has been heated, it expands and no longer passes through the ring. It does so, however, on reverting to its original temperature. The expansibility of liquids and gases, which is far greater than that of solids, is easily shown. For a liquid, a glass tube with a bulb at one end may be used (fig. 191), which is filled with some liquid, coloured alcohol or mercury, for instance. When the bulb is gently heated, by placing it in tepid water for example, the column of liquid is seen to rise considerably in the tube; thus from *a* to *b*.

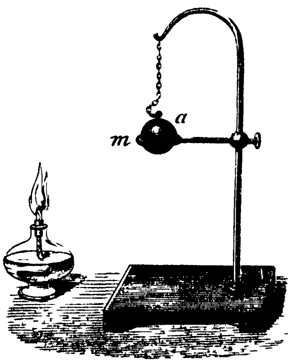


Fig. 190.

The experiment may be made in a similar manner with gases; yet, as they are far more expansible than liquids, a long tube, bent twice, may be fused to the bulb tube, as represented in fig. 192. An index of mercury, *m*, is introduced in the tube, which is effected by gently heating the bulb so as to expel some of the air; a drop of mercury being then placed in the funnel, *a*, on cooling, the air in the bulb and the tube contracts, and the pressure of the atmosphere forces the droplet to *m*, for instance. The apparatus being thus arranged, if the bulb is held in the hand for a few moments,

the enclosed air expands sufficiently to force the index from *m* to *n*, an expansion which is far greater than in the case of liquids.

It will thus be seen that the general effect of heat upon bodies is to expand them. Yet this only applies to bodies which, like the metals, glass, etc., do not absorb moisture. Bodies which absorb moisture, such as wood, paper, clay, undergo a contraction when heated; owing to the increase of temperature expelling moisture from their pores. Thus a moist sheet of paper placed before the fire coils up on the heated side. Coopers, too, in order to curve the staves of barrels, heat them on one side, by lighting a fire on the inside of the barrel when the staves are placed close together. The part turned towards the fire contracts in drying, and curves on the side exposed to the direct action of heat.

Fig. 191.

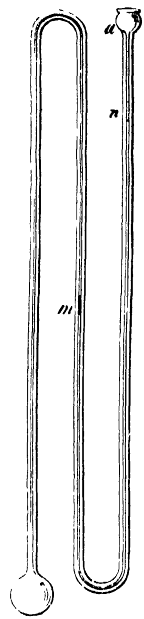


Fig. 192.

MEASUREMENT OF TEMPERATURES. THERMOMETRY.

202. **Temperature.**—The *temperature* or *hotness* of a body may be defined as being the greater or less extent to which it tends to impart sensible heat to other bodies. The temperature of any particular body is varied by adding to it or withdrawing from it a certain amount of sensible heat. The temperature of a body must not be confounded with the *quantity* of heat it possesses; a body may have a high temperature and yet have a very small quantity of heat, and conversely a low temperature may yet possess a large amount of heat. If a cup of water be taken from a bucketful, both will indicate the same temperature, yet the quantities of heat they possess will be very different. The subject of the quantity of heat will be afterwards more fully explained in the chapter on SPECIFIC HEAT.

203. **Thermometers.**—*Thermometers* are instruments for measuring temperatures. Owing to the imperfections of our senses we are unable accurately to measure temperatures by the sensations of

heat or cold which they produce in us, and for this purpose recourse must be had to the physical effects of heat upon bodies. The most accurate and the most convenient are the effects of expansion. Solids, having but little expansibility, can only be used to examine large intervals of temperature ; gases, on the other hand, are very expansible, and only serve to measure small alterations of temperature. They are, moreover, affected by changes of atmospheric pressure. For these reasons, liquids are best suited for the construction of ordinary thermometers. Mercury and alcohol are the only ones used—the former because its expansion is regular, and it only boils at a very high temperature ; and the latter because it does not solidify even at the greatest known cold.

Fig. 193.

Fig. 194.

The mercurial thermometer is the one most extensively used. It consists of a capillary glass tube, at the end of which is blown the *bulb*, a cylindrical or spherical reservoir (fig. 193). Both the bulb and a part of the stem are filled with mercury and the expansion is measured by a scale graduated either on the stem itself (fig. 197), or on a frame to which it is attached (fig. 200).

The filling of the tube with mercury may be effected by fusing to the tube a small funnel as shown in fig. 193. In this is placed a small quantity of mercury, and the bulb is then gently heated by a spirit lamp. The expanded air partially escapes by the funnel, and, on cooling, the air which remains contracts, and a portion of the mercury passes into the bulb. The bulk is then again warmed, and allowed to cool, a fresh quantity of mercury enters, and so on, until the bulb and part of the tube are full of mercury. The mercury is then heated to boiling ; the mercurial vapour in escaping carries with it the air and moisture which remain in the tube. The tube, being thus full of the expanded mercury and of mercurial vapour, is hermetically sealed at one end. When the thermometer is cold the mercury ought to fill the bulb and a portion of the stem.

204. **Graduation of the thermometer.**—The thermometer having been filled, as has just been described, the mercury rises or sinks in the stem, whenever the temperature rises or sinks, and these variations furnish a means of measuring temperatures. For this purpose a graduated scale must be constructed along the stem. In graduating the scale two points must be taken, which represent definite fixed temperatures and which can always be easily produced.

Experiment has shown that ice always melts at the same point whatever be the degree of heat, and that distilled water under the same pressure, and in a vessel of the same kind, always boils at the same temperature. Consequently, for the first fixed point, or *zero*, the temperature of melting ice has been taken; and, for a second fixed point, the temperature of boiling water in a metal vessel under the standard atmospheric pressure of 30 inches.

This interval of temperature—that is, the range from zero to the boiling point—is taken as the unit for comparing temperatures; just as a certain length, a foot or a yard for instance, is used as a basis for comparing lengths.

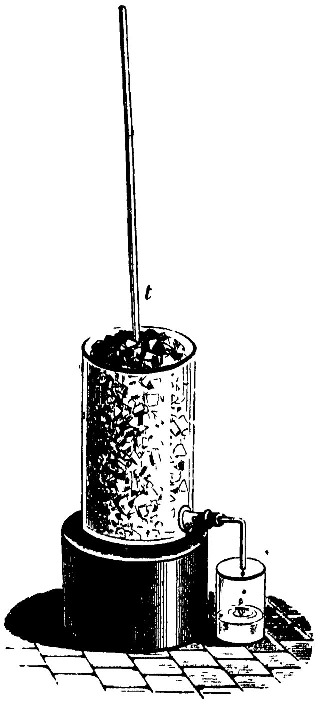


Fig. 195.

To obtain zero, snow or pounded ice is placed in a vessel, in the bottom of which is an aperture by which water escapes (fig. 195). The bulb and a part of the stem of the thermometer are immersed in this for about a quarter of an hour; the mercury sinks, and the level at which it finally rests—*t*, for instance—is marked by tying a piece of thread round the stem.

The second fixed point is determined by means of the apparatus represented in fig. 196. It consists of a tin plate vessel containing distilled water, in the lid of which is a long tube. The ther-

mometer is placed in this by means of a cork, and the water heated to boiling. The thermometer is thus surrounded by steam, which, liberated from the liquid, escapes by the lateral apertures. This steam is at the same temperature as the water from which it is liberated, and, when the mercury is stationary, a second mark is made upon the stem.

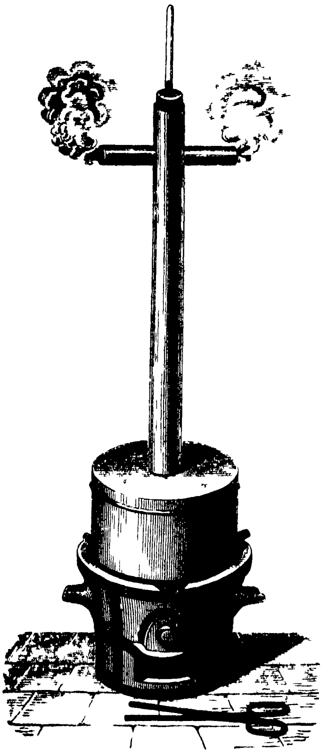


Fig. 196.

205. **Construction of the scale.**—Just as the foot-rule which is adopted as the unit of comparison for length is divided into a number of equal divisions called inches, for the purpose of having a smaller unit of comparison, so likewise the unit of temperatures, the range from zero to the boiling point, must be divided into a number of parts of equal capacity called *degrees*. There are three methods by which this is done. On the Continent, and more especially in France, this space is divided into 100 parts, and this division is called *Centigrade* or *Celsius* scale ; the latter being the name of the inventor. The centigrade thermometer is almost exclusively adopted in foreign scientific works, and, as its use is gradually extending in this country, it has been and will be adopted in this book.

The degrees are designated by a small cipher placed a little above on the right of the number, which marks the temperature, and to indicate temperatures below zero the minus sign is placed before them. Thus -15° signifies 15 degrees below zero. In accurate thermometers the scale is marked on the stem itself (fig. 197). It cannot be displaced, and its length remains fixed, since glass has very little expansibility. This marking is effected by covering

the stem with a thin layer of wax, and then marking the divisions of the scale, as well as the corresponding numbers, with a steel point. The thermometer is then exposed for about ten minutes to the vapours of a substance called *hydrofluoric acid*, which bites into the glass where the wax has been removed. The rest of the wax is then dissolved off by means of turpentine, and the stem is found to be permanently etched.

Fig. 197.

Scales are also constructed on plates of ivory, wood, or metal, against which the stem is placed. Fig. 200 represents this arrangement.

Besides the *Centigrade* scale, two others are frequently used—*Fahrenheit's scale* and *Réaumur's scale.*

In Réaumur's scale, which is used in Russia and in North Germany, the fixed points are the same as on the Centigrade scale, but the distance between them is divided into 80 degrees instead of into 100. That is to say, 80 degrees Réaumur are equal to 100 degrees Centigrade; one degree Réaumur is equal to $\frac{100}{80}$ or $\frac{5}{4}$ of a degree Centigrade, and one degree Centigrade equals $\frac{80}{100}$ or $\frac{4}{5}$ degree Réaumur. Consequently to convert any number of Réaumur degrees into Centigrade degrees (20 for example), it is merely necessary to multiply them by $\frac{5}{4}$ (which gives 25). Similarly, Centigrade degrees are converted into Réaumur's by multiplying them by $\frac{4}{5}$.

The thermometer scale invented by Fahrenheit in 1714 is still much used in England, and also in Holland and North America. The higher point is like that of the other scales, the temperature of boiling water, but the null-point or zero is the temperature obtained by mixing equal weights of sal-ammoniac and snow, and the interval between the two points is divided into 212 degrees. The zero was selected because the temperature was the lowest then known, and was erroneously thought to represent *absolute cold.* When Fahrenheit's thermometer is placed in melting ice it stands at 32 degrees; and, therefore, 100 degrees on the Centigrade scale are equal to 180 degrees on the Fahrenheit scale, and thus 1 degree Centigrade is equal to $\frac{9}{5}$ degree Fahrenheit, and conversely 1 degree Fahrenheit is equal to $\frac{5}{9}$ of a degree Centigrade.

If it is required to convert a certain number of Fahrenheit degrees (95 for example) into Centigrade degrees, the number 32 must be first subtracted, in order that the degrees may count from the same point of the scale. The remainder in the example is thus

63, and, as 1 degree Fahrenheit is equal to $\frac{5}{9}$ of a degree Centigrade, 63 degrees are equal to $63 \times \frac{5}{9}$ or 35 degrees Centigrade.

If F be the given temperature in Fahrenheit's degrees and C the corresponding temperature in Centigrade degrees, the former may be converted into the latter by means of the formula

$$(F - 32)\tfrac{5}{9} = C,$$

and conversely, Centigrade degrees may be converted into Fahrenheit by means of the formula

$$\tfrac{9}{5}C + 32 = F.$$

These formulæ are applicable to all temperatures of the two scales, provided the signs are taken into account. Thus, to convert the temperature of 5 degrees Fahrenheit into Centigrade degrees we have

$$(5 - 32)\tfrac{5}{9} = \frac{-27 \times 5}{7} = -15^\circ \text{ C.}$$

In like manner we have for converting Réaumur's into Fahrenheit's degrees the formula

$$\tfrac{9}{4}R + 32 = F,$$

and conversely, for changing Fahrenheit's into Réaumur's degrees, the formula

$$(F - 32)\tfrac{4}{9} = R.$$

206. **Alcohol thermometer.**—The *alcohol thermometer* differs from the mercurial thermometer in being filled with coloured alcohol. But as the expansion of liquids is less regular in proportion as they are near the boiling point, alcohol, which boils at 78° C., expands very irregularly. Hence, alcohol thermometers are usually graduated by placing them in baths at different temperatures together with a standard mercurial thermometer, and marking the corresponding temperatures.

Fig. 198

The filling is effected by gently heating the bulb so as to expel

a certain quantity of air, then inverting it and plunging the open end into alcohol (fig. 198). The air inside contracts on cooling, and the atmospheric pressure raises the alcohol in the tube and in the bulb. It does not at first fill it completely, for some air remains : but the alcohol is then boiled, and its vapour expels all the air ; the tube is then again inverted and placed in alcohol, and now the instrument fills completely. The further construction resembles that of a mercurial thermometer.

207. **Limits to the employment of mercurial thermometers.**—Of all thermometers in which liquids are used, the one with mercury is the most useful, because this liquid expands most regularly, and is easily obtained pure, and because its expansion between -36° and 100° is *regular*—that is, proportional to the degree of heat. It also has the advantage of having a very low specific heat (260). But for temperatures below -36° C. the alcohol thermometer must be used, since mercury solidifies at -40° C. to a mass like lead. Above 100 degrees the coefficient of expansion increases and the indications of the mercurial thermometers are only approximate, the error amounting sometimes to several degrees. Mercurial thermometers also cannot be used for temperatures above 350°, for this is the boiling point of mercury.

Observations by means of the thermometer.—In taking the temperature of a room, the thermometer is usually suspended against the wall. This may, however, give rise to an error of several degrees ; for if the wall communicates with the outside, and especially if it has a northern aspect, it will, generally speaking, be colder than the air in the room, and will communicate to the thermometer too low a temperature. On the other hand, it may happen that the wall becomes too much heated by the sun's rays, or by chimney flues, and then the thermometer will be too high. The only way to obtain with accuracy the temperature of the air in a room is to suspend the thermometer by a string in the centre at a distance from any object which might raise or lower its temperature. The same remark applies to the determination of the temperature of the atmosphere ; the thermometer must be suspended in the open air, in the shade ; and not against a wall.

208. **Leslie's differential thermometer.**—Sir John Leslie constructed a thermometer for showing the difference of temperature of two neighbouring places, from which it has received the name *differential thermometer.* It consists of two glass bulbs containing air, and joined by a bent glass tube of small diameter fixed on a

frame (fig. 199). Before the apparatus is sealed, a coloured liquid is introduced in sufficient quantity to fill the horizontal part of the tube and about half the vertical legs. It is important to use a liquid which does not give off vapour at ordinary temperatures, and dilute sulphuric acid coloured with litmus is generally preferred. The apparatus being closed, the air is passed from one bulb into the other, by heating them unequally, until the level of the liquid is the same in both branches. A zero is marked at each end of the liquid column. To graduate the apparatus, one of the bulbs is raised to a temperature 10° higher than the other. The air of the first is expanded and causes the column of liquid, *ba*, to rise in the other leg. When the column is stationary the number 10 is marked on each side at the level of the liquid, the distance between zero and 10 being divided into 10 equal parts, both above and below zero, on each leg.

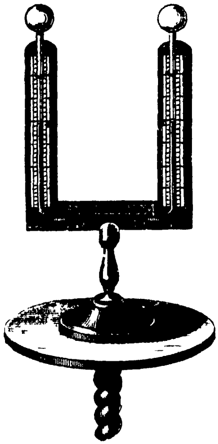


Fig 199

209. **Rutherford's maximum and minimum thermometers.**—It is necessary, in meteorological observations, to know the highest temperature of the day, and the lowest temperature of the night. Ordinary thermometers could only give these indications by a

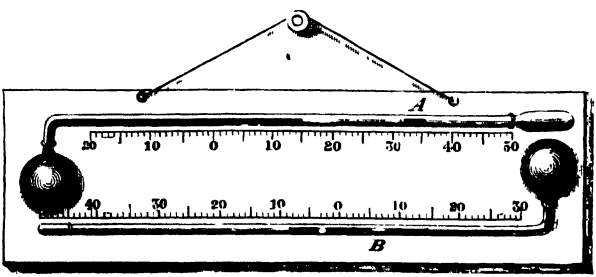


Fig. 200.

continuous observation, which would be impracticable. Several instruments have accordingly been invented for this purpose, the simplest of which is Rutherford's. On a rectangular piece of plate

glass (fig. 200) two thermometers are fixed, whose stems are bent horizontally. The one, A, is a mercury, and the other, B, an alcohol, thermometer. In A there s a small piece of iron wire, A, moving freely in the tube, which serves as an index. The thermometer being placed horizontally, when the temperature rises the mercury pushes the index before it. But as soon as the mercury contracts, the index remains in that part of the tube to which it has been moved, for there is no adhesion between the iron and the mercury. In this way the index registers the highest temperature which has been obtained ; in the figure this is 32°. The position of the index is easily adjusted by means of a small magnet. In the minimum thermometer there is a very minute hollow glass tube which serves as index. When it is at the end of the column of liquid, and the temperature falls, the column contracts and carries the index with it, in consequence of adhesion, until it has reached the greatest contraction. When the temperature rises, the alcohol expands, and, passing between the sides of the tube and the index, does not displace B. The position of the index gives therefore the lowest temperature which has been reached : in the figure this is 5 degrees below zero.

One of the most important of the uses of the thermometer is in observing the temperature of the body. This, which is usually 98° F., may vary within a degree or so even in perfectly healthy persons,

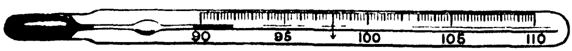


Fig. 201.

but greater variations indicate some disturbance, and the thermometer has become a most valuable criterion of the existence and course of disease, more especially those of a febrile character. For this purpose a special kind of maximum thermometer is graduated, showing only those portions of the scale which have to be observed, fig. 201. Such thermometers are called *clinical thermometers.*

210. **Pyrometers.**—The name *pyrometer* is given to instruments for measuring temperatures so high that mercurial thermometers could not be used. The older contrivances for this purpose, Wedgwood's, Daniell's (which in principle resembled the apparatus in fig. 189), Brongniart's, etc., are gone entirely out of use. None of them gives an exact measure of temperature, and the methods now used depend either on the expansion of gases, or on thermo-electricity (Book VIII. Chapter xiii.).

CHAPTER II.

RADIATION OF HEAT.

211. **Radiant heat.**—If we stand in front of a fire, or expose ourselves to the sun's heat, we experience a sensation of warmth which is not due to the temperature of the air; for if a screen be interposed, the sensation immediately disappears, which would not be the case if the surrounding air had a high temperature. Hence bodies can send out rays which excite heat, and which penetrate through the air without heating it, just as rays of light pass through transparent bodies. Heat thus propagated is said to be *radiated*; and we shall use the term *ray of heat* or *thermal* or *calorific ray*, in a similar sense to that in which we shall afterwards use the term *ray of light* or *luminous ray*.

The rays of heat are not warm of themselves any more than the rays of light are luminous; they represent the direction in which heat is propagated, and only produce a heating effect when they fall upon a body and are absorbed by it. If they are transmitted they do not raise the temperature of a body. The upper layers of the atmosphere and the celestial spaces are at a lower temperature than any known on the earth.

If a stream of cold water be continuously passed through a hollow glass lens, on one side of which the sun's rays fall, a piece of tinder placed in the focus on the other side is easily ignited.

We shall find that the property of radiating heat is not confined to incandescent substances, such as a fire, or a lamp, or a red-hot ball, but that bodies of all temperatures radiate heat. Thus a bottle full of hot water and a bottle full of cold water both emit heat; the first emits more as compared with the second, the greater the difference of temperature between the two.

212. **Laws of radiation.**—The radiation of heat is governed by three laws.

I. *Radiation takes place in all directions round a body.* If a thermometer be placed in different positions round a heated body,

it indicates everywhere a rise in temperature; at equal distances from the source of heat it indicates the same rise in temperature.

II. *Heat is propagated in a right line.* For, if a screen be placed in the right line which joins the source of heat and the thermometer, so as to stop the rays, the latter is not affected.

But in passing obliquely from one medium into another, as from air into a glass, calorific, like luminous, rays become deviated, an effect known as *refraction.* The laws of this phenomenon are the same for heat as for light, and they will be more fully discussed under the latter subject.

III. *Radiant heat is propagated in a vacuum as well as in air.* This is directly demonstrated by the following experiment :–

In the bottom of a glass flask a thermometer is fixed in such a manner that its bulb occupies the centre of the flask (fig. 202). The neck of the flask is next carefully narrowed by means of the blow-pipe, and then the apparatus having been suitably attached to an air-pump, a vacuum is produced in the interior. This having been done, the tube is sealed by the blow-pipe at the narrow part. On immersing this apparatus in hot water, or on bringing near it some hot charcoal, the thermometer is at once seen to rise. This could only be due to radiation through the vacuum in the interior, for glass is so bad a conductor that the heat could not travel with this rapidity through the sides of the flask and the stem of the thermometer.

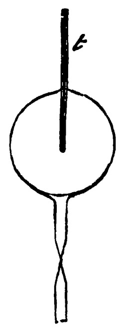


Fig. 202.

213. **Causes which modify the intensity of radiant heat.**—The *intensity of radiant heat* transmitted to us by heated bodies depends on the temperature of the source of heat, and on its distance. The laws by which it is regulated may be thus stated :—

I. *The intensity of radiant heat is proportional to the temperature of the source.*

II. *The intensity of radiant heat is inversely as the square of the distance.*

The first law is demonstrated by placing a metal box containing water at 10°, 20°, or 30°, successively at equal distances from the bulb of a differential thermometer. The temperatures indicated by the latter are then found to be in the same ratio as those of the box; for instance, if the temperature of that corresponding to the box at 10° be 2°, those of the others will be 4° and 6° respectively.

The second law is demonstrated experimentally by placing the differential thermometer at a certain distance from the source of heat, a yard for instance, and then removing it to double the distance. In the latter case, the amount of heat received is not one-half but one-quarter. If the distance be three yards the quantity of heat is one-ninth, and so forth.

214. **Interchange of heat among all bodies.**—Owing to the radiation which is continually taking place in all directions round a body, there is a continual interchange of heat. If the bodies are all at the same temperature, each one sends to the surrounding ones a quantity equal to that which it receives, and their temperatures remain stationary. But if their temperatures are unequal, as the hot bodies emit more heat than they receive, they therefore sink in temperature : while, as the bodies of lower temperatures receive more heat than they emit, their temperature rises ; thus the temperatures are all ultimately equal. The radiation does not stop ; it goes on, but without loss or gain from each body, and this condition is accordingly known as the *mobile equilibrium of temperature.*

From what has been said it will be understood that bodies, placed in our rooms, all tend to assume a uniform temperature ; generally speaking this is not the case, for many causes concur in cooling one set, and in heating the others. Thus bodies, placed near a wall, cooled by the outer air, find a cause for cooling. Those, on the contrary, which are at the top of the room, tend to acquire a higher temperature ; for as heated air rises as being less dense, the layers nearest the ceiling are always hotter than the lower ones.

From this continual interchange of heat there is necessarily a limit to the cooling of bodies, for they always tend to resume on the one hand what they lose on the other. To have an indefinite cooling, a body should be suspended in space, not receiving heat from any body. As it would then lose heat without acquiring any, there is no telling to what extent its temperature would sink.

CHAPTER III.

REFLECTION OF HEAT. REFLECTING, ABSORBING, AND EMISSIVE POWERS.

215. **Law of the reflection of heat.**— When the rays emitted by a source of heat fall upon the surface of a body, they are divided generally into two parts : one, which passing into the mass of a body is absorbed, and raises the temperature; the other,

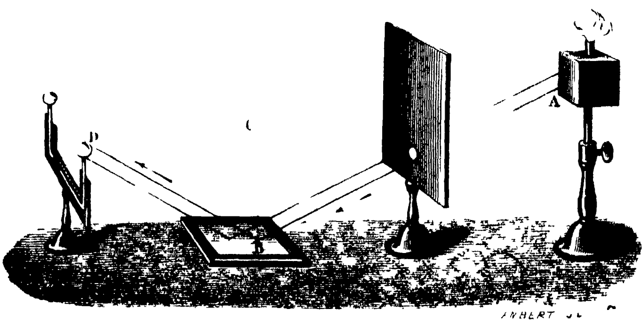


Fig. 203

which darts off from the surface like an elastic ball striking against a hard body ; this is expressed by saying that these rays are *reflected.* Thus let A be the source of heat, a cubical box filled with hot water (fig. 203), and near it a screen which does not allow heat to pass, but near the bottom of which is an aperture. If, behind this screen, a polished surface, B, be placed, on which the rays emitted by the cube impinge, and beyond this again a differential thermometer, D, the latter indicates an increase of temperature when one of its bulbs is so placed that it receives the rays reflected by the polished body. In this experiment, rays like AB which fall on the reflecting surface are called *incident* rays, from a Latin word which signifies to fall ; and the *angle of incidence* is not the angle

which they make with the reflecting surface, but the angle ABC, which they make with a straight line, BC, perpendicular to this surface. In like manner the angle CBD, which the reflected rays make with the same straight line, is called the *angle of reflection.*

The reflection of heat is always subject to the law, that *the angle of reflection is equal to the angle of incidence.* We shall subsequently see that the reflection of light is governed by the same law.

216. **Reflection of heat from concave mirrors.**—The effects of the reflection of heat may be very powerful when it takes place from the surface of *concave mirrors*, which are spherical surfaces of glass or of metal. These mirrors may be regarded as being made up of

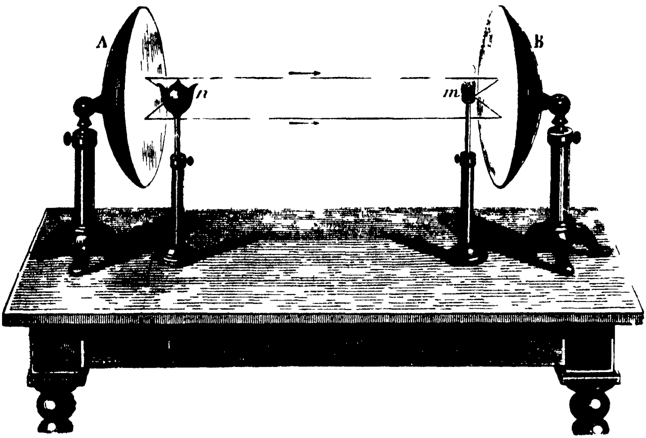


Fig. 204.

an infinite number of extremely small planes inclined towards each other, in such a manner as to determine the curvature. From the symmetrical grouping of these small facets, it follows that when a group of rays falls upon a concave mirror, these rays, in obedience to the laws of reflection, coincide in a single point, to which the name *focus* (from the Latin word for a *hearth*) is applied, to express the great quantity of heat which is concentrated there (167).

In treating of light we shall discuss in detail the properties of the focus of concave mirrors; for the present it will be sufficient to describe experiments which demonstrate the great intensity which radiant heat may acquire when concentrated in these points. Fig. 204 represents an experiment which is frequently made in physical

lectures. Two reflectors, A and B (fig. 204), are arranged at a distance of 4 to 5 yards, and so that their axes coincide. In the focus of one of them, A, is placed a small basket *n*, containing a red-hot iron ball. In the focus of the other, B, is placed an inflammable body, such as gun-cotton, or phosphorus. The rays emitted from the focus, *n*, are first reflected from the mirror, A, in a direction parallel to the axis; and impinging on the other mirror, B, are reflected so that they coincide in the focus, *m*. That this is so is

Fig. 205

proved by the fact that the inflammable substance placed in this point takes fire, which is not the case if it is above or below it.

The same effect may be produced by the sun's rays. For this purpose a concave reflector is so placed that the sun's rays strike directly against it (fig. 205); if then a combustible substance, such as paper, wood, cork, etc., be held by means of a pincette in the focus, these bodies are seen to take fire. The effect produced depends on the magnitude of the mirror. With a mirror having an *aperture* of 6 feet—that is, the distance from one edge to the

other—copper and silver are soon melted; and silicious stones and flints have been softened and even melted.

In consequence of the high temperatures produced in the foci of concave mirrors and of the facility with which combustible bodies may be ignited there, they have been called *burning mirrors.* It is stated that Archimedes burnt the Roman vessels before Syracuse by means of such mirrors. Buffon constructed burning mirrors of such power as to prove that the feat attributed to Archimedes was possible. The mirrors were made of a number of silvered plane mirrors each about 8 inches long by 5 broad. They could be turned independently of each other in such a manner that the rays reflected from each coincided in the same point. With 128 such mirrors and a hot summer's sun Buffon ignited a plank of tarred wood at a distance of 70 yards.

217. **Reflecting power of various substances.**—It has been seen that heat which falls upon a body is always divided into two

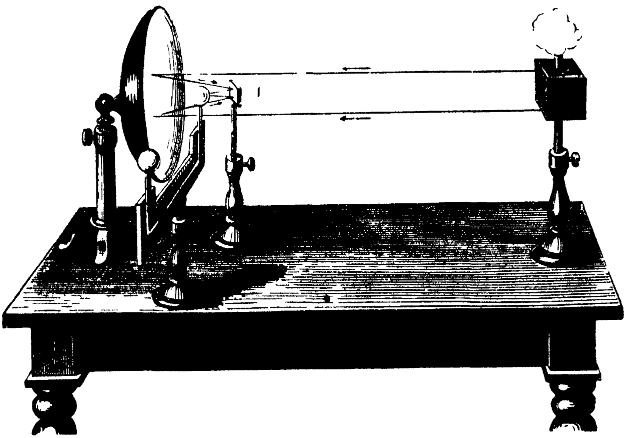


Fig. 206.

parts, one which is reflected from the surface, and the other which passes into the mass of the body, and raises its temperature. The quantities of heat thus absorbed, or reflected, vary in different substances; one set reflects much and absorbs little, which is expressed by saying that they have a great *reflecting power*; others, on the contrary, reflect very little heat, but absorb a great deal

and are therefore spoken of as having great *absorbing power.* It is clear that these properties are the inverse of each other, for any body which absorbs much heat can reflect but little, and conversely.

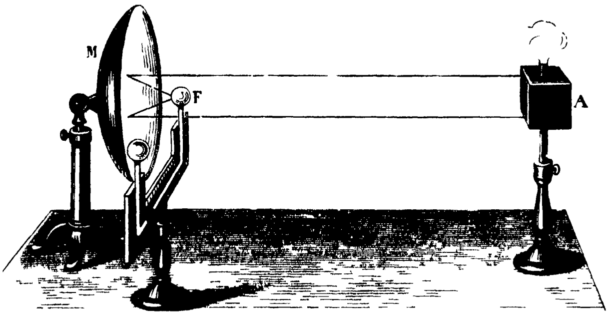
In order to compare the reflecting powers of various substances, Leslie took as a source of heat a tin plate cube full of boiling water, which he placed in front of a concave mirror (fig. 206). The rays emitted from this towards the reflector tended after reflection to become concentrated at the focus F. In front of this were placed successively small square plates of paper, glass, metal—in short, of all the substances whose reflecting power was to be examined. As shown in the drawing, these rays, after a first reflection from the mirror, were reflected a second time from these plates, and finally impinged against the bulb of a differential thermometer. Now, in this experiment the source of heat was the same, as was also the distance from the reflector; yet the thermometer indicated very various degrees of heat according to the material of which the small plates were formed. The temperature was highest when the plate was made of polished brass, which metal is therefore the best reflector. The reflecting power of silver is only $\frac{9}{10}$ that of brass; that of tin $\frac{8}{10}$; of glass $\frac{1}{10}$. Water and lampblack were found to be destitute of reflecting power, for when the plates were coated with lampblack, or moistened with water, the thermometer indicated no increase in temperature, showing that it received no heat.

218. **Absorbing power.**—In order to compare the absorbent powers of various substances, Leslie arranged the experiment as shown in fig. 207. The source of heat and the reflector being the same as in the preceding experiment, the differential thermometer was placed in the focus, where it received directly all the heat reflected by the mirror. The surface of the *focal* bulb was altered for each experiment by coating it successively with various materials, paper, tinfoil, gold, silver, copper, and leadfoil; it was also coated with a thin layer of lampblack; it was moistened, and so on. It was thus found that when the focal bulb was coated with lampblack, or with water, the thermometer indicated the highest temperatures; whence it was concluded that lampblack and water have the greatest absorbing power. The lowest temperature was exhibited when the bulb was coated with thin metal foil, more especially with silver; thus indicating that these substances absorb the least proportion of the heat which is of the temperature of boiling water (222). The result was arrived at, which could, indeed,

be foreseen, that those bodies which best reflect heat absorb it least; and that, conversely, the best absorbents are the worst reflectors.

219. **Emissive power.**—The *emissive* or *radiating* power is the property bodies have of emitting more or less easily the heat they contain; it is the inverse of the absorbing power.

Leslie compared the emissive powers of various bodies by means of the apparatus represented in fig. 207. The focal bulb of the thermometer was left uncoated, and the various substances were applied successively to the sides of the tin cube. One of them, for instance, was left in its ordinary condition; the second was coated



with lampblack; to the third a sheet of white paper was fixed, and to the fourth a glass plate.

Turning first of all the blackened face towards the reflector, the thermometer indicated a considerable increase of temperature, thus showing that the cube sent much heat towards the reflector. Turning then successively the other faces towards the reflector, it was found that the paper side emitted less heat than the blackened face, but more than the glass side, which in turn emitted more than the tin side.

Working in this manner, Leslie found that lampblack has the greatest emissive power, then paper, then ordinary glass, then the metals. The order of their emissive powers is thus the same as

that of their absorbing powers. It is thus concluded that bodies which best absorb heat, also radiate best ; and Dulong and Petit have proved that for each substance the emissive power is in all cases proportional to the absorbing power.

220. **Causes which modify the reflecting, absorbing, and radiating powers.**—As the radiating and absorbing powers are equal, any cause which affects the one affects the other also. And as the reflecting power varies in an inverse manner, whatever increases this diminishes the radiating and absorbing powers, and *vice versâ.*

It has been already stated that these different powers vary with different bodies, and that metals have the greatest reflecting power and lampblack the feeblest. In the same body these powers are modified by the degree of polish, the density, the thickness of the radiating substance, the obliquity of the incident or emitted rays, and, lastly, by the nature of the source of heat.

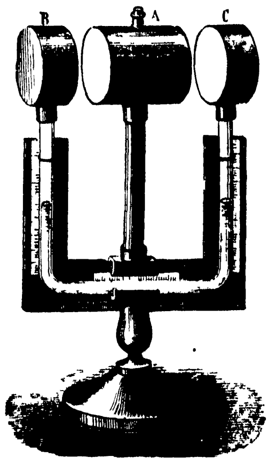


Fig. 208.

The relation between the absorbing and radiating powers is well illustrated by the following experiment (fig. 208), which represents what is in effect a differential thermometer (208), with polished metal canisters, B and C, instead of glass bulbs. These are connected by a glass tube in which stands coloured liquid. Between them is a metal canister, A, which can be filled with hot water. The faces of B and of A which look to the right are coated with lampblack; those of C and A which face the left are bright an polished. Thus of two opposite faces one is black and the other bright; hence when the cylinder A is filled with hot water, its white face radiates towards the black face of B, and its black face towards the white face of C, and the liquid in the stem does not move, showing that they are at the same temperature. On the one hand the greater emissive power of the black face of A is compensated by the sallmer absorptive power of the white face of C ; while on the other hand the feebler radiating power of the white face of A is made up by the greater absorbing power of the black face of B.

If, however, the canister be turned round so that the two black or the two bright faces are opposite one another the liquid at once moves.

It has been usually assumed that the reflecting power increases with the polish of the surface, and that the other powers diminish therewith. But Melloni showed that by scratching a polished metallic surface its reflecting power was sometimes diminished and sometimes increased. This phenomenon he attributed to the greater or less density of the reflecting surface. If the plate had been originally hammered, its homogeneity would be destroyed by this process, the molecules would be closer together on the surface than in the interior, and the reflecting power would be increased. But if the surface is scratched, the internal and less dense mass becomes exposed, and the reflecting power diminished. On the contrary, in a plate which has not been hammered, and which is homogeneous, the reflecting power is increased when the plate is scratched, because the density at the surface is increased by the scratches.

The absorbing power varies with the inclination of the incident rays. It is greatest at right angles ; and it diminishes in proportion as the incident rays deviate from the perpendicular direction. This is one of the reasons why we receive more heat from the sun in summer than in winter ; because, in the former case, the sun's rays are less oblique.

The radiating power of gaseous bodies in a state of combustion is feeble, as is seen by bringing the bulb of a thermometer near a hydrogen flame, or the flame of an ordinary Bunsen's burner, the temperature of which is very high. But if a platinum spiral be placed in this flame, it assumes the temperatute of the flame, and radiates a considerable quantity of heat, as is indicated by the thermometer. It is for a similar reason that the flames of oil and of gas lamps radiate more than a hydrogen flame in consequence of the excess of carbon which they contain, and which, not being entirely burned, becomes white-hot in the flame.

The absorbing power of a body is also influenced by the nature of the source of heat. Thus for the same quantity of heat emitted, a surface coated with white lead absorbs twice as much, if the heat comes from a cube filled with hot water as it does if the heat is that of a lamp. Lampblack, on the contrary, under the same conditions, absorbs the same amount of heat whatever be the source.

221. **Different kinds of heat. Diathermaneity.**—Just as different subtances possess the power of allowing the rays of light to pass through them to different extents, and are said to be more or less *transparent* (311), so also modern investigation has shown that all bodies do not allow the rays of heat to traverse them with equal facility, and are therefore said to be more or less *diathermanous*. For instance, the metals are just as *athermanous* for heat rays as they are *opaque* for the rays of light. On the other hand, rock salt stands in the same relation to heat rays that a perfectly colourless and transparent body, such as glass, does to luminous rays. It is perfectly diathermanous.

One and the same substance may be diathermanous to varying extents for *heat from different sources*. Thus colourless glass allows the sun's rays to pass through it with facility, but less so the heat emitted by a flame, or by an incandescent body, and far less again the heat of a cube filled with boiling water, which is known as a *Leslie's cube* (217). Water allows the sun's rays to traverse it partially, but stops the obscure heat. Again, alum is colourless and transparent for light, but almost entirely diathermanous for obscure rays.

A body which is opaque for light may be diathermanous for certain kinds of heat. Thus, a solution of iodine in bisulphide of carbon is perfectly opaque for the rays of light, but is traversed by obscure heat rays with facility.

In investigating the diathermaneity of bodies, Melloni used the thermo-multiplier, for a description of which we must refer to Book VIII. Chapter xiii. He first of all placed the thermo-multiplier at a certain distance from a source of heat, and, having observed the deflection, he determined to what extent this was enfeebled by the interposition of various bodies, such as plates of glass, alum, and rock salt. In like manner he used various sources of heat—for instance, the sun, an oil or spirit lamp, a red-hot spiral of platinum wire, a heated blackened metal plate, or a Leslie's cube: and he concluded that there are *different kinds of heat rays* or different *colours of heat*, with regard to which various diathermanous substances behave just as coloured transparent substances do in regard to different kinds of light. Thus when white light traverses red glass, only the red rays are transmitted, all other kinds being absorbed. If this red light falls on another red glass, it traverses it without being weakened; but is completely absorbed by blue glass. Similar results are met with in regard to the rays of heat: for in-

stance, heat which has passed through a glass plate would traverse another plate without much loss, but would be almost completely stopped by a plate of alum.

222. **Applications.**—The property which bodies possess of absorbing, emitting, and reflecting heat meets with numerous applications in domestic economy and in the arts. Leslie stated that white bodies reflect heat very well, and absorb very little, and that the contrary is the case with black substances. This principle is not universally true, as Leslie supposed; for example, white lead has as great an absorbing power for non-luminous rays as lamp-black. But it holds good in regard to absorbents like cloth, cotton, wool, and other organic substances when exposed to luminous heat, such as that of the sun's rays. Accordingly, the most suitable coloured clothing for summer is just that which experience has taught us to use—namely, white, for it absorbs less of the sun's rays than black clothing, and hence feels cooler.

The polished fire-irons before a fire are cool, whilst the black fender is often unbearably hot. If a liquid is to be kept hot as long as possible, it must be placed in a brightly polished metallic vessel, for then, the emissive power being less, the cooling is slower. It is for this reason advantageous that the steam pipes, etc., of locomotives should be kept brightly polished.

Snow is a powerful reflector, and, therefore, neither absorbs nor emits much heat; owing to its small emissive power it protects from cold the ground and the plants which it covers; and owing to its small absorbing power it melts but slowly during a thaw. A branch of a tree, a bar of metal, a stone in the midst of a mass of snow, accelerate the fusion by the heat they absorb, and which they radiate about them.

In the Alps the mountaineers accelerate the fusion of the snow by covering it with earth, which increases the absorbing power.

Metal and other cooking vessels should be black and rough on the outside, for then their absorbing power is greater and they become heated more rapidly. If their surface be bright and polished a greater quantity of fuel is required to heat them. This is what is seen in vessels of silver and of white porcelain. In common unglazed earthenware, liquids are more rapidly heated, but also more rapidly cooled.

It is observed that grapes and other fruits ripen sooner when they are placed in contact with a black wall (mortar mixed with lampblack). This arises from the fact that from the great emissive

power of the wall, as well as from its great absorbing power, it becomes more highly heated under the influence of the sun and gives up more heat to the fruit.

Glass is used for fire-screens ; for, while it allows the cheerful light of the fire to pass, it stops most of the heat from this source. It is, however, very transparent for the heat of the sun, allowing almost all its light and heat to pass.

In gardens, the use of glass shades and of greenhouses depends on the diathermancy of glass for heat from luminous rays, and on its athermancy for obscure heat. The heat which radiates from the sun is mainly of the former class, but by its contact with the earth it is changed into obscure heat, which as such cannot retraverse the glass. This explains the manner in which greenhouses accumulate heat, and also the great warmth in summer of rooms with glass roofs.

A mercury thermometer, the bulb of which is blackened by being coated with lampblack, will indicate a rise of temperature where an ordinary one is unaffected. If one of the bulbs of a differential thermometer be coated with lampblack and the other be left unaltered, and both be exposed to the same source of heat, the blackened one will show the higher temperature.

A piece of bright tinfoil upon which the sun's rays are brought to a focus by means of a lens will be fused with difficulty, or not at all ; but if the surface is coated with lampblack it will melt in the focus at once.

CHAPTER IV.

CONDUCTING POWER OF BODIES.

223. **Conducting power of solids.**—In the phenomena of radiation which have been considered, heat is transmitted from one body to another through space, without raising the temperature of the medium through which it passes. It may also be propagated through the mass of a body, from molecule to molecule.

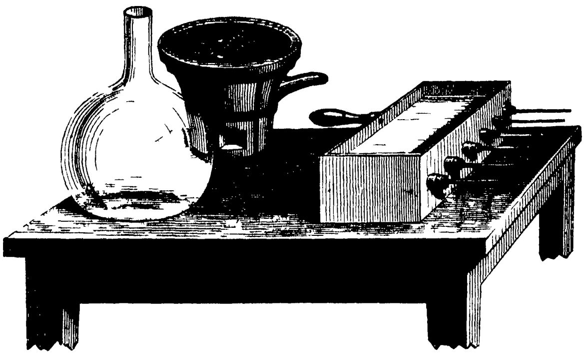


Fig. 209.

This internal propagation in the mass of a body is called *conductivity*, or conducting power ; and *good conductors* are those bodies which readily transmit heat in their mass, while those through which it passes with difficulty are called *bad conductors.*

Organic substances conduct heat badly. De la Rive and De Candolle have shown that woods conduct better in the direction of their fibres than in a transverse direction; and have remarked upon the influence which this feeble conducting power, in a transverse direction, exerts in preserving a tree from sudden changes of temperature, enabling it to resist alike a sudden abstraction of heat from within, and the sudden accession of heat from without. Tyndall

has also shown that this tendency is aided by the low conducting power of the bark, which is in all cases less than that of the wood.

Cotton, wool, straw, bran, powdered gypsum, etc., are all bad conductors.

In order to compare the conducting power or *conductivity* of different solids, Ingenhaus constructed the apparatus which bears his name, and which is represented in fig. 209. It is a metal trough, in which, by means of tubulures and corks, are fixed rods of the same dimensions, but of different materials: for instance, iron, copper, wood, glass. These rods extend to a slight distance in the trough, and the parts outside are coated with wax, which melts at 61°. The box being filled with boiling water, it is observed that the wax melts to a certain distance on the metal rods, while on the others there is no trace of fusion. The conducting power is evidently greater in proportion as the wax has fused to a greater distance. The experiment is sometimes modified by attaching glass balls or marbles to the ends of the rods by means of wax. As the wax melts, the balls drop off, and this in the order of their respective conductivities. By these and other experiments it has been ascertained that metals are the best conductors, then marble, porcelain, brick, wood, glass, etc.

224. **Conducting power of liquids. Manner in which they are heated.**—Liquids, with the exception of mercury, which is a metal, are all bad conductors of heat. They conduct so imperfectly that Rumford assumed water to be entirely destitute of conducting power. But the fact that water, as well as other liquids, does conduct heat, though only to a small extent, has been established by the most careful and accurate experiments.

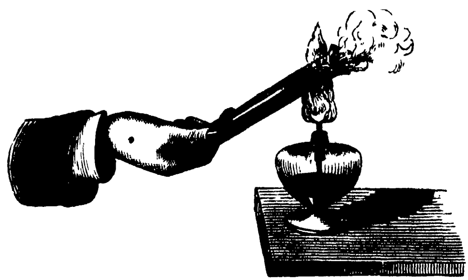


Fig. 210.

From their small conducting power, liquids are not heated in the same manner as solids. If heat be applied to a solid, whether on the top, the bottom, or the sides, it is transmitted from layer to layer, and the whole mass becomes heated. This is not the case

with a liquid; if it is heated at the top, the heat is only propagated with extreme slowness, and it cannot be completely heated throughout; indeed, if the experiment be made as represented in figure 210, the top layer of water may be heated to boiling, while at a little distance there is no appreciable increase of temperature. But if it be heated at the bottom, the temperature of the liquid rapidly rises. This, however, is not owing to its conductivity, but to ascending and descending currents, which are produced throughout the whole mass of liquid.

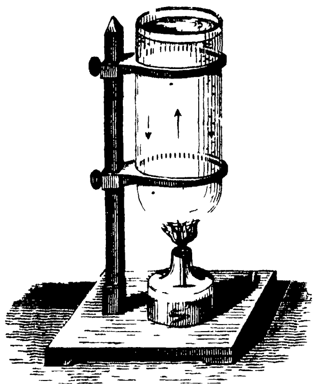


Fig. 211.

The existence of these currents may be demonstrated by placing in the water a powder of nearly the same density—for instance, oak sawdust—and then gently heating the vessel at the bottom, fig. 211. As the lower layers of the liquid become heated they expand, while the upper layers, which are colder and therefore denser, sink and take the place of the first; these in their turn become heated, rise, and so on, until the entire mass is heated. These currents are evident from the sawdust, which is seen to rise slowly in the centre and to re-descend near the edges. This mode of heating is said to be by *convection.*

225. **Conductivity of gases.**—Gases are extremely bad conductors of heat; but this cannot be easily demonstrated by experiment, owing to the extreme mobility of their particles. For, so soon as they are heated in any part of their mass, expansions and currents are produced, in virtue of which the heated parts mingle with the cold ones; hence a general elevation of temperature, which we might be tempted to consider as due to conductivity, but which is really *convection.* When, however, gases are hindered in their motion, their conductivity seems extremely small, as shown by many examples in the following article.

That there is a difference in gases as regards their conductivity for heat may be seen from the following experiment. A_1 and A, fig. 212, are two similar vessels standing in a mercury trough, one of them containing air, and the other hydrogen. In the caps stout copper

wires are inserted which are joined by fine platinum wires a_1 and a. When the ends are connected with the poles of a voltaic battery, a current of electricity circulates through the wires. This we shall afterwards see (476) has the property of heating anything through which it passes, and the rise of temperature is higher the thinner the wire. On passing the current it will be found that while the wire in air is heated to redness, the one in hydrogen remains quite dull.

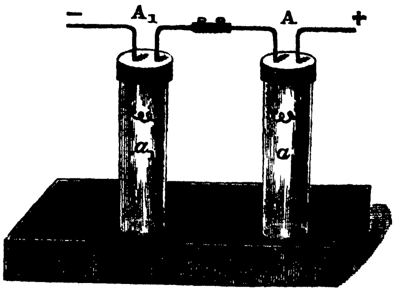


Fig. 212.

Now the heat produced by the passage of the current is the same in both the wires, for they are exactly alike, and accordingly the difference can only be due to the fact that the heat is more rapidly carried away by the hydrogen than by the air; in other words, that hydrogen is a better conductor.

226. **Applications.**—The greater or less conductivity of bodies for heat meets with numerous applications. If a liquid is to be kept warm for a long time, it is placed in a vessel and packed round with non-conducting substances, such as shavings, straw, bruised charcoal. For this purpose water pipes and pumps are wrapped in straw at the approach of frost. The same means are used to hinder a body from becoming heated. Ice is transported in summer by packing it in bran, or by folding it in flannel.

Double walls constructed of thick planks having between them any finely divided materials such as shavings, sawdust, dry leaves, etc., retain heat extremely well; they are likewise advantageous in hot countries, for they prevent its access. If a layer of asbestos, a very fibrous substance, is placed on the hand, a red-hot iron ball can be held without inconvenience. Red-hot cannon balls can be wheeled to the gun's mouth in wooden barrows partially filled with sand. Lava has been known to flow over a layer of ashes underneath which was a bed of ice, and the non-conducting power of the ashes has prevented the ice from fusion. The porosity of snow forms a covering which protects seed and young grain from frost. In fireproof safes the hollow sides are filled with wood ashes, or powdered gypsum, or ignited alum.

The clothes which we wear are not warm in themselves; they

only hinder the body from losing heat, in consequence of their spongy texture and the air they enclose. The warmth of bed-covers and of counterpanes is explained in a similar manner. Double windows are frequently used in cold climates to keep a room warm —they do this by the non-conducting layer of air interposed between them. For the same reason two shirts are warmer than one of the same material, but of double the thickness. Hence, too, the warmth of furs, eider down, etc.

That water boils more rapidly in a metallic vessel than in one of porcelain of the same thickness ; that a burning piece of wood can be held close to the burning part with the naked hand, while a piece of iron heated at one end can only be held at a great distance, are easily explained by reference to their various conductivities.

The sensation of heat or cold which we feel when in contact with certain bodies is materially influenced by their conductivity. If their temperature is lower than ours, they appear colder than they really are, because, from their conductivity, heat passes away from us. If, on the contrary, their temperature is higher than that of our body, they appear warmer, from the heat which they give up at different parts of their mass. Hence it is clear why carpets, for example, are warmer than wooden floors, and why the latter again are warmer than stone floors.

The small conducting power of felt is used in the construction of the *Norwegian stove*, which consists merely of a wooden box with a thick lining of felt in the inside. In the centre is a cavity in which can be placed a stew-pan provided with a cover. On the top of this is a lid, also made of felt, so that the pan is surrounded by a very badly conducting envelope. Meat, with water and suitable additions, is placed in the pan, and the contents are then raised to boiling. The whole is then enclosed in the box and left to itself; the cooking will go on without fire, and after the lapse of several hours it will be quite finished. The cooling down is very slow, owing to the bad conducting power of the lining ; at the end of three hours the temperature is usually not found to have sunk more than from 10° to 15°.

The closer the contact of the hand with a substance, the greater is the difference of temperature felt. With smooth surfaces there are more points of contact than with rough ones. A hot glass rod feels hotter than a piece of rusted iron of the same temperature, although the latter is a better conductor. The closer the substance is pressed, the more intimate the contact ; an ignited piece of charcoal can be lifted by the fingers, if it is not closely pressed.

CHAPTER V.

MEASUREMENT OF THE EXPANSION OF SOLIDS, LIQUIDS, AND GASES.

227. **Expansion of solids.**—The expansion of bodies by heat being a general effect which exerts its influence on all bodies, and is continually changing their volume, it will be readily understood that the determination of the amount of this expansion is a problem of great importance, both in its purely scientific as well as in its practical aspects. We shall first describe the method of determining the expansion of solids. We have already seen that the expansion of solids may be either as regards the length or the volume. Hence the investigation of the expansion of solids may be divided into two parts, the first relating to *linear*, and the second to *cubical*, expansion.

Linear expansion. In order to compare with each other the expansion of bodies, the elongation is taken which a certain length of the substance undergoes when it is heated from zero to 1 degree, and this elongation is called the *coefficient of linear expansion.* The coefficients of a great number of substances were accurately determined towards the end of the last century by Lavoisier and Laplace. They took a bar of the substance to be determined, placed it in melting ice, and then accurately determined its length. Having placed it then in a bath of boiling water, they again measured its length. They then observed an elongation, which represented the total expansion between zero and 100°—that is, for an increase of temperature of 100 degrees. This, divided by 100, gave the coefficient of linear expansion for one degree. In this manner the following numbers were obtained.

Coefficients of linear expansion for 1° *between* 0° *and* 100° *C.*

White glass	0·00000861	Bronze	0·000018167
Platinum	0·00000884	Brass	0·000018782
Steel	0·00001079	Silver	0·000019097
Iron	0·00001220	Tin	0·000021730
Gold	0·00001466	Lead	0·000028575
Copper	0·00001718	Zinc	0·000029417

It will be seen from this table that the coefficients of expansion are in all cases very small. Thus, when we say that the coefficient of expansion of copper is about 0·000017, we mean that a rod of this metal when heated through 1 degree will expand by 17 millionths of its length; that is to say, a rod of copper a million feet in length would be longer by 17 feet under these circumstances.

Cubical expansion. The *coefficient of cubical expansion* is the increase in volume for a temperature of one degree. Calculation shows that the coefficient of cubical expansion of a solid is three times the coefficient of its linear expansion; and these coefficients may therefore be obtained by multiplying the above numbers by three.

228. **Applications of the expansion of solids.**—In the arts we meet with numerous examples of the influence of expansion. (i.) The bars of furnaces must not be fitted tightly at their extremities, but must, at least, be free at one end, otherwise, in expanding they would exert sufficient force to split the masonry. (ii.) In making railways a small space is left between the successive rails, for, if they touched, the force of expansion would cause them to curve, or would break the chairs. (iii.) Water pipes are fitted to one another by means of telescopic joints, which allow room for expansion. (iv.) If a glass is heated or cooled too rapidly it cracks; this arises from the fact that glass being a bad conductor of heat, the sides become unequally heated, and consequently unequally expanded, and the strain thereby produced is sufficient to cause a fracture.

When bodies have been heated to a high temperature, the force produced by their contraction on cooling is very considerable: it is equal to the force which is needed to compress or expand the material to the same extent by mechanical means. According to Barlow, a bar of malleable iron a square inch in section is stretched $\frac{1}{10000}$th of its length by a weight of a ton; the same increase is experienced by about 9° C. A difference of 45° C. between the cold of winter and the heat of summer is not unfrequently experienced in this country. In that range a wrought-iron bar ten inches long will vary in length by $\frac{1}{200}$th of an inch, and will exert a strain, if its ends are securely fastened, of five tons.

An application of this contractile force is seen in the mode of securing the tires on wheels. The tire being made red hot, and thus considerably expanded, is placed on the circumference of the wheel, and then cooled. The tire, when cold, clasps the wheel

with such force as not only to secure itself on the rim, but also to press home the ends of the spokes into the felloes and nave. Another interesting application was made in the case of a gallery at the Conservatoire des Arts et Métiers in Paris, the walls of which had begun to bulge outwards. Iron bars were passed across the building, and screwed into plates on the outside of the walls. Each alternate bar was then heated by means of lamps, and when the bar had expanded it was screwed up. The bars, being then allowed to cool, contracted, and in doing so drew the walls together. The same operation was performed on the other bars.

229. **Spiral thermometer.**—An interesting example of the application of the expansion of solids is met with in a form of maximum and minimum thermometer devised by Herman and Pfister. It consists (fig. 213) of a strip of steel a yard long, rather less than half an inch wide, and about the twentieth of an inch thick, to which is soldered a brass strip of the same dimensions. It is bent in a spiral, *s*, the steel being outermost. One end is fixed at *a*, the other end, *b*, is free. At a certain definite temperature this end has a certain position. If the temperature rises, the brass expands more than the steel, and the free end is moved towards the left; if the temperature sinks it moves towards the right.

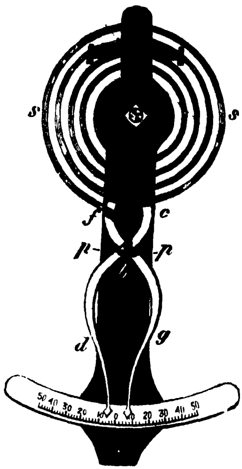


Fig. 213.

This motion of the spiral is transmitted to two indicators, *cd* and *fg*, on which are minute rods, *p* and *p*. If the temperature rises, the rod *p*, together with its index *cd*, is pushed forward until the maximum temperature is reached, and, as there is a gentle friction, remains in that position. If, on the contrary, the temperature sinks, the index *fg* is moved to the right until the lowest temperature is obtained. The instrument is graduated specially by comparing its indications with the corresponding temperatures shown by a mercurial thermometer.

230. **Compensation pendulum.**—An important application of the expansion of metals has been made in *the compensation pendulum*. To understand the utility of such an arrangement, we must call to mind what has been said about pendulums (59): namely, that

their oscillations are *isochronous*—that is, are made in equal times—and that their application to the regulation of clocks depends upon this property. But we have also seen that the duration of an oscillation depends on the length of the pendulum; the longer the pendulum, the more slowly it oscillates, and, therefore, the shorter it is, the more rapidly does it oscillate. Hence a pendulum formed of a single rod terminated by a metal bob, *c*, as represented in fig. 56, could not be an exact regulator of time; for, as the temperature rises, it would lengthen, and the clock would go slower; the exact opposite would take place when it contracted by cooling. These inconveniences have been remedied by taking the remedy from the cause of the evil.

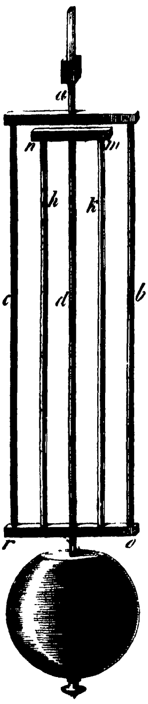


Fig. 214.

For this purpose the pendulum rod consists of several metal bars arranged as represented in fig. 214. The rods *a*, *b*, *c*, *d*, are of steel, and all expand in a downward direction when the temperature rises, thus making the bob sink. The rod *d*, supporting the bob, is fixed to a cross-piece *nm*, which in turn is fastened to two rods *k* and *h*, which are connected to the piece *ro*, and therefore cannot expand downwards, but only in an upward direction; they raise the piece *mn*, and with it the bob. In order, therefore, that this latter shall neither rise nor sink, it is necessary that the upward expansion of the rods *k* and *h* shall exactly compensate the downward expansion of the rods *a c b d*.

Brass being more expansible than steel, compensation is effected by taking the first metal for the rods *h* and *k*, and the second for the rods *a*, *b*, *c*, and *d*. The only condition necessary for compensation is that *the lengths of the two metals must be inversely as their coefficients of expansion*. That is to say, that if brass is two or three times as expansible as steel, the sum of the lengths of the brass rods must be one-half or one-third that of the steel rods.

A difference of the $\frac{1}{100}$ of an inch in the length of the pendulum would cause a clock to vary ten seconds in twenty-four hours, and an alteration in temperature of 14° C. would produce this difference.

EXPANSION OF LIQUIDS.

231. **Absolute and apparent expansion.**—We have already seen that liquids are more expansible than solids (201), which is a consequence of their feebler cohesion ; but their expansibility is far less regular, and the less so the nearer their temperature approaches that of their boiling point.

In solids, two kinds of expansion have to be considered, the longitudinal and the cubical. Now, it is clear that the latter is the only kind of expansion which can be observed in the case of liquids. The expansion may be either *real or apparent.* The former is the real increase in volume which a liquid assumes when it is heated ; while the latter is that which the eye actually observes ; that produced in the vessel containing the liquid. Thus in thermometers, when the liquid expands and rises in the stem, the apparent expansion is observed, which is less than the real or absolute expansion. For, while the mercury expands, the bulb of the thermometer does so too : its volume is greater, and hence the liquid does not rise so high in the stem as it would if the volume of the bulb were rigidly unaltered.

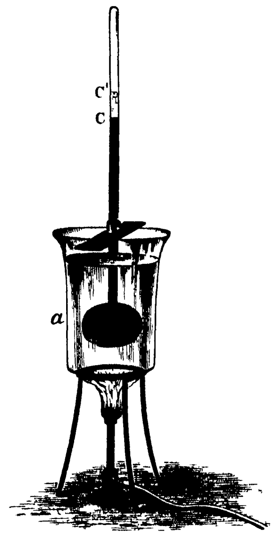


Fig. 215.

If a bulb of thin glass, fig. 215, provided with a narrow stem, containing some coloured liquid, be immersed in a beaker of hot water, the column of liquid in the stem at first sinks from the mark C′, at which it originally stood, to the mark C, but then immediately after rises, and continues to do so until the liquid inside has the same temperature as the hot water. The first sinking of the liquid is not due to its contraction ; it arises from the expansion of the glass, which becomes heated before the heat can reach the liquid ; but the expansion of the liquid soon exceeds that of the glass, and the liquid then ascends.

Hence, since, whatever be the nature of the material in which a liquid is contained, it has some expansibility, and always expands

with the liquid, the apparent expansion is the only one directly observed in liquids.

The coefficient of expansion of a liquid is the increase which a given volume experiences for a rise in temperature of one degree. These coefficients greatly vary with different liquids. In a glass vessel the apparent expansion of mercury is 1·5 parts in ten thousands; that of water is 4·6 parts, that is, three times as great; alcohol is still more expansible, for its coefficient is 11·6 parts in ten thousands, or a little over 1 part in a thousand.

232. **Maximum density of water.**—Water presents the remarkable phenomenon that when its temperature sinks it contracts up to 4°; but from that point, although the cooling continues, it expands up to the freezing point, so that 4° represents the point of greatest contraction of water, or what is called its *point of maximum density.*

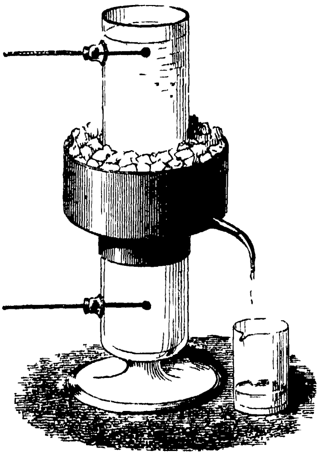


Fig 216.

These phenomena may be observed by comparing a water thermometer—one, that is to say, filled with water, with one of mercury; both being exposed to gradually diminishing temperature.

Hope used the following method to determine the maximum density of water. He took a deep vessel perforated by two lateral apertures, in which he fixed thermometers (fig. 216), and, having filled the vessel with water at 0°, he placed it in a room at a temperature of 15°. As the layers of liquid at the sides of the vessel became heated they sank to the bottom, and the lower thermometer marked 4°, while that of the upper one was still at zero. Hope then made the inverse experiment: having filled the vessel with water at 15°, he placed it in a room at zero. The lower thermometer, having sunk to 4°, remained stationary for some time, while the upper one cooled down until it reached zero. Both these experiments prove that water is heavier at 4° than at 0°, for in both cases it sinks to the lower part of the vessel. This experiment may be adapted for lecture illustration by

using a cylinder containing water at 15° C., partially surrounded by a jacket containing bruised ice (fig. 216).

This phenomenon is of great importance in the economy of nature. In winter the temperature of lakes and rivers falls, from being in contact with the cold air, and from other causes, such as radiation. The colder water sinks to the bottom, and a continual succession of currents is formed, until the whole has a temperature of 4°. The cooling on the surface still continues, but the cooled layers, being lighter, remain on the surface, and ultimately freeze. The ice formed thus protects the water below, which remains at a temperature of 4°, even in the most severe winters, a temperature at which fish and other inhabitants of the water are not destroyed.

EXPANSION OF GASES.

233. **Value of the coefficient of expansion of gases.**—Not merely are gases the most expansible of all bodies, but their expansion is the most regular. It was originally assumed, on the basis of Gay-Lussac's experiments, that all gases expanded to the same extent for the same increase of temperature—that is, that they had all the same coefficient of expansion. It has, however, been established that the coefficients of various gases do present slight differences. They are, however, so slight that for ordinary practical purposes they may be assumed to be the same ; that is to say, 367 parts in a hundred thousand ; or, in other words, 100,000 volumes of air, or any other gas, when heated through 1 degree Centigrade, would become 100,367 volumes, or 273 volumes would become 274. This expansibility is about 13 times as great as that of water.

234. **Effects of the expansion of gases.**—The expansion of gases affords us numerous important applications, not merely in domestic economy, but also in atmospheric phenomena. Thus in our dwellings, when the air is heated and vitiated by the presence of a great number of persons, it expands and rises in virtue of its diminished density to the highest parts of rooms ; and, to allow this to escape, apertures are made in the cornice, while fresh and pure air enters by the joints of the doors and of the windows.

When in winter the door of a warm room is put ajar, and a lighted candle held near the top, fig. 217, the direction of the flame proves the existence of a current of warm air from the inside to the outside. If we lower the flame, it will be found that at about the

middle it is not affected by any air current, but that lower down, near the ground, the flame is driven inwards.

In theatres the spectators in the galleries are exposed to the highest temperature and the most impure air, while those near the orchestra breathe in a purer air.

Draughts in chimneys are due to the expansion of air. Heated by the fire in the grate, the air rises in the chimney with a velocity which is greater the more it is expanded. Hence results a rapid current of air, which supports and quickens the combustion by constantly renewing the oxygen absorbed.

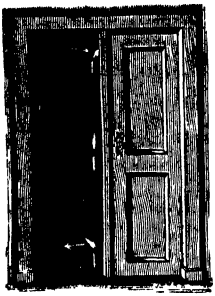


Fig. 217.

The expansion and contraction of air have a fortunate influence on the temperature of that part of the atmosphere in which we live. For when the ground is strongly heated by the sun's burning rays, the layers of air in immediate contact with it tend to acquire the same temperature and to form a stifling atmosphere ; but these layers, gradually expanding, rise in virtue of their lessened density ; while the higher layers, which are colder and denser, gradually replace them. Thus the high temperature which would otherwise be produced in the lower regions is moderated, and never exceeds the limits which plants and animals can support.

The expansions and contractions produced in the atmosphere over a large tract of country are the cause of all winds, from the lightest zephyr to the most violent hurricane. These winds, which at times are so destructive, so capricious in their direction, and so variable in their strength, not merely have the effect of mixing the heated and the cooler part of the atmosphere, and of thus moderating extremes of temperature, but by driving away the vitiated atmosphere of our towns, and replacing it by pure air they are one of the principal causes of salubrity ; without them our cities would be the centres of infection, where epidemic diseases of all kinds would be permanent. Without winds, clouds would remain motionless over the country where they were formed, neither rivers nor brooks would moisten the soil, and the greater part of the globe would be condemned to absolute dryness. But, carried by the winds, the clouds formed above the seas are transported to the centres of continents, where they condense and fall as rain ; and

this having fertilised the soil gives rise to the numerous rivers which fall into the ocean, thereby establishing a continuous circulation from the seas towards the continents, and from continents towards seas.

235. **Density of gases.**—The densities of solids and of liquids have been determined in reference to water (103); those of gases by comparison with air: that is, having taken as a term of comparison, or *unity*, the weight of a certain volume of air, the weights of the same volume of other gases are determined. But as gases are very compressible and expansible, and as, therefore, their densities may greatly vary, they must be reduced to a definite pressure and temperature. This is why *the temperature of zero* and *the pressure of* 30 *inches* have been chosen.

Hence the *relative density* of a gas, or its *specific gravity*, is the relation of the weight of a certain volume of the gas to that of the same volume of air; both the gas and the air being at zero and under a pressure of 30 inches.

In order, therefore, to find the specific gravity of a gas, oxygen, for instance, it is necessary to determine the weight of a certain volume of this gas, at a pressure of 30 inches, and a temperature of zero, and then the weight of the same volume of air under the same conditions. For this purpose a large globe of about two gallons capacity is used, like that represented in fig. 97, the neck of which is provided with a stop-cock, which can be screwed to the air-pump. The globe is first weighed empty, and then full of air, and afterwards full of the gas in question. The weights of the gas and of the air are obtained by subtracting the weight of the exhausted globe from the weights of the globe filled, respectively, with air and gas. The quotient, obtained by dividing the latter by the former, gives the specific gravity of the gas. It is difficult to make these determinations at the same temperature and pressure, and therefore all the weights are reduced by calculation to zero, and the standard pressure of 30 inches.

In this manner the following densities have been found:—

Air	1·0000	Oxygen	1·1056
Hydrogen	0·0692	Carbonic acid	1·5290
Nitrogen	0·9714	Chlorine	2·4400

From these numbers the lightest of gases, and therefore of all bodies, is hydrogen, whose density is less than $\frac{1}{14}$ that of air.

CHAPTER VI.

CHANGES OF STATE OF BODIES BY THE ACTION OF HEAT.

236. **Fusion.**—In treating of the general effects of heat, we have seen that its action is not only to expand bodies, but to cause them to pass from the solid to the liquid state, or from the latter state to the former, according as the temperature rises or falls; then from the liquid to the aëriform state, or conversely. These various changes of state we shall now investigate under the name of *fusion, or melting*, *solidification*, *vaporisation*, and *liquefaction*.

Fusion, or melting, is the passage of a solid body to the liquid state by the action of heat. This phenomenon is produced when the force of cohesion which unites the molecules is balanced by the force of repulsion (4); but as the cohesive force varies in different substances, the temperature at which bodies melt does so likewise. For some substances this temperature is very low, and for others very high, as the following table shows:—

Melting points of certain substances.

Mercury	−38·8°	Tin	228°
Bromine	12·5	Bismuth	264
Ice	0	Lead	335
Butter	+33	Zinc	422
Phosphorus	44	Antimony	450
Potassium	55	Silver	1000
Stearine	60	Gold	1250
White wax	65	Iron—cast	1150
Sodium	90	„ wrought	1600
Sulphur	114	Iridium	1950

Some substances, however, such as paper, wood, wool, and certain salts, do not fuse at a high temperature, bnt are decomposed. Many bodies have long been considered *refractory*—that, is incapable of fusion; but, in the degree in which it has been possible to produce higher temperatures, their number has diminished. Gaudin succeeded in fusing rock crystal by means of a lamp fed

by a jet of oxygen ; and Despretz, by combining the effects of the sun, the voltaic battery, and the oxy-hydrogen blow-pipe, melted alumina and magnesia, and softened carbon so that it was flexible, which is a condition near that of fusion.

Some substances pass from the solid to the liquid state without showing any definite melting point ; for example, glass and iron become gradually softer and softer when heated, and pass by imperceptible stages from the solid to the liquid condition. This intermediate condition is spoken of as the state of *vitreous fusion.* Such substances may be said to melt at the lowest temperature at which perceptible softening occurs, and to be fully melted when the further elevation of temperature does not make them more fluid ; but no precise temperatures can be given as their melting points.

237. **Laws of fusion.**—It has been experimentally found that the fusion or melting of bodies is governed by the two following laws :—

I. *Every substance begins to fuse at a certain temperature, which is invariable for one and the same substance if the pressure be constant.*

II. *Whatever be the intensity of the source of heat, from the moment fnsion commences, the temperature of the body ceases to rise, and remains constant until the fusion is complete.*

For instance, the melting point of ice is zero, and a piece of this substance exposed to the sun's rays, or placed in front of a fire or over a lamp, could never be heated beyond this temperature. Exposure to a more intense heat would only hasten the fusion ; the temperature would remain at zero until the whole of the ice was melted.

Alloys are generally more fusible than any of the metals of which they are composed ; for instance, an alloy of 5 parts of tin and 1 of lead fuses at 194°. The alloy known as *Rose's fusible metal,* which consists of 4 parts of bismuth, 1 part of lead, and 1 of tin, melts at 94°, and an alloy of 1 or 2 parts of cadmium with 2 parts of tin, 4 parts of lead, and 7 or 8 parts of bismuth, known as *Wood's fusible metal,* melts between 66° and 71° C. Fusible alloys are of extended use in soldering and in taking casts.

A mixture of the chlorides of potassium and of sodium fuses at a lower temperature than either of its constituents ; the same is the case with a mixture of the carbonates of potassium and sodium, especially when they are mixed in the proportion of their chemical equivalents.

An application of this property is met with in the case of *fluxes*, which are much used in metallurgical operations. They consist of substances which, when added to an ore, partly by their chemical action, help the reduction of the substance to the metallic state, and, partly, by presenting a readily fusible medium, hasten the agglomeration of the particles and thus promote the formation of a regulus.

238. **Latent heat.**—Since, during the passage of a body from the solid to the liquid state, the temperature remains constant until the fusion is complete, whatever be the intensity of the source of heat, it must be concluded that, in changing their condition, bodies absorb a considerable amount of heat, the only effect of which is to maintain them in the liquid state. This heat, which is not indicated by the thermometer, is called *latent heat* or *latent heat of fusion*, an expression which, though not in strict accordance with modern ideas, is convenient from the fact of its universal recognition and employment.

An idea of what is meant by latent heat may be obtained from the following experiment. If a pound of *water* at 80° is mixed with a pound of water at zero, the temperature of the mixture is 40°. But if a pound of pounded *ice* at zero is mixed with a pound of water at 80°, the ice melts, and two pounds of water at *zero* are obtained. The pound of ice at zero is changed into a pound of water also at zero, but as the hot water is also lowered to this temperature, what has become of the 80° of heat it possessed? They exist in the water which results from the ice; their effect has neither been to increase its temperature nor its volume, but simply to impart fluidity to it. Consequently, the mere change of a pound of ice to a pound of water at the same temperature requires as much heat as will raise a pound of water through 80°. This quantity of heat represents the *latent heat of the fusion of ice*, or the *latent heat of water*.

Every substance in melting absorbs a certain amount of heat, which, however, varies materially with different substances.

The enormous quantity of heat absorbed by ice in melting explains how it is that so long a time is required for thaw. And conversely, it is owing to the latent heat of water that, even when its temperature has been reduced to zero, so long a time is required before it is entirely frozen. Before it can be so the water must give out the heat which had been consumed in its liquefaction; it becomes, as it were, a source of heat which retards the solidification.

Faraday calculated that the heat given out by a cubic yard of water in freezing is equal to that which would be produced by the complete combustion of a bushel of coals.

Were it not for the great amount of heat which must be absorbed by snow or ice in melting, we should, on a change from frost to mild weather, be liable to the most destructive floods, owing to the sudden melting of the accumulated snow and ice.

239. **Solidification.**—Those substances which are liquefied by heat revert to the solid state on cooling, and this passage from the liquid to the solid state is called *solidification*. If this solidification takes place at a low temperature, it is spoken of as *congelation* or *freezing*.

In all cases the phenomenon is subject to the following laws :—

I. *Every body, under the same pressure, solidifies at a fixed temperature, which is the same as that of fusion.*

II. *From the commencement to the end of the solidification, the temperature of a liquid remains constant.*

Thus if lead begins to melt at 335°, melted lead in like manner, when cooled down, begins to solidify at 335°. Moreover, until it is completely solidified, the temperature remains constant at 335°. This arises from the fact that the liquid metal, in proportion as it solidifies, restores the heat it had absorbed in being melted. The same phenomenon is observed whenever a liquid solidifies (238).

Many liquids, such as alcohol, ether, and bisulphide of carbon, do not solidify or freeze even at the lowest known temperature. Pure water freezes at zero ; olive and rape oils at $-6°$; linseed and nut oils at $-27°$.

If water contains salts, or other foreign bodies, its freezing point is lowered. Sea water freezes at $-2·5°$ to $-3°$ C. ; the ice which forms is quite pure, and a saturated solution remains. In Holland advantage is taken of this property to concentrate sea water for the purpose of extracting salt from it. If water contains alcohol, precisely analogous phenomena are observed; the ice formed is pure, and, practically, all the alcohol is contained in the residue.

Water presents the remarkable phenomenon that when it solidifies and forms ice, its volume undergoes a material increase. In speaking of the maximum density of water we have already seen that, on cooling, it expands from 4 degrees to zero ; it further expands on the moment of solidifying, or contracts on melting by about 10 per cent. One volume of ice at 0° gives 0·908 of water

at 0°, or 1 volume of water at 0° gives 1·102 of ice at the same temperature.

The increase of volume in the formation of ice is accompanied by an expansive force which sometimes produces powerful mechanical effects, of which the bursting of water pipes and the breaking of jugs and bottles containing water are familiar examples. The splitting of stones, rocks, and the swelling up of moist ground during frost are caused by the fact that water penetrates into the pores and there becomes frozen. The bursting of water pipes takes place during frost, but the solid ice usually closes the crack and prevents any escape of water, and the ill effects only show themselves when the thaw has set in, and the ice is melted.

The expansive force of ice was strikingly shown by some experiments of Major Williams in Canada. Having quite filled a 13-inch iron bomb-shell with water, he firmly closed the touch-hole with an iron plug weighing 3 pounds, and exposed it in this state to the frost. After some time the iron plug was forced out with a loud explosion, and thrown to a distance of 415 feet, the shell was cracked, and a mass of ice projected from the crack as shown in fig. 218.

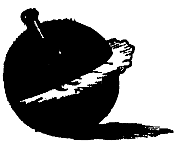


Fig. 218.

From the expansion which water undergoes in freezing, it is obvious that ice must be less dense than water ; and this in fact is the case, for ice floats on the surface of the water. In the polar seas, where the temperature is always very low, masses of floating ice are met with which are called *ice-fields*. They rise out of the sea to a height of as much as 4 or 5 yards, and are immersed to a depth of at least eleven times as much, and they frequently extend over 40 miles. True mountains of ice, or *icebergs*, are found floating on those seas ; they have not the same area, but attain very great heights. One measured in Melville Bay was 315 feet in height, and three-quarters of a mile in length.

Cast-iron, bismuth, and antimony expand on solidifying, like water, and can thus be used for casting ; but gold, silver, and copper contract, and hence coins of these metals cannot be cast, but must be stamped with a die.

240. **Crystallisation.**—When bodies pass slowly from the liquid to the solid state, their molecules, instead of becoming grouped in a confused manner, generally acquire a regular order and arrangement, in virtue of which these bodies assume the geometrical shapes of cubes, pyramids, and prisms, etc., which are perfectly definite,

and are known as *crystals.* Flakes of snow, when looked at under the microscope (293), ice in the process of formation, sugar candy, rock crystal, alum, nitre, common salt, and many other substances afford well-known instances of crystallisation.

Two methods are in use for crystallising substances ; the *dry way* and the *moist way.* By the first method bodies are melted by heat, and then allowed to cool slowly. The vessel in which the operation is performed becomes lined with crystals, which are made apparent by inverting the vessel and pouring out the excess of liquid before the whole of it is melted. Sulphur, bismuth, and many other metals are thus easily crystallised. The second method

Fig. 219.

consists in dissolving in hot water the substance to be crystallised, so as to form a saturated solution, which is then allowed to cool slowly. The body is thereby deposited on the sides of vessels in crystals, which are larger and better shaped, the more slowly the crystallisation is effected. In this manner sugar candy and salts are crystallised. Fig. 219 represents a mass of crystals of alum obtained in this way.

241. **Solution.**—A body is said to *dissolve* when it becomes liquid in consequence of an attraction between its molecules and those of a liquid. Gum arabic, sugar, and most salts dissolve in water. Bees' wax does not dissolve in water, but does so in turpentine. The weight dissolved generally increases with the

temperature. When a liquid has dissolved as much as it can at a particular temperature, it is said to be *saturated.*

During solution, as well as during fusion, a certain quantity of heat always becomes latent, and hence it is that the solution of a substance usually produces a diminution of temperature. In certain cases, however, instead of the temperature being lowered, it actually rises, as when caustic potass is dissolved in water. This depends upon the fact that during the solution of a solid in a liquid two simultaneous and contrary phenomena are produced. The first is the passage from the solid to the liquid condition, which always lowers the temperature. The second is the *chemical* combination of the body dissolved with the liquid, and which, as in the case of all chemical combinations, produces an increase of temperature. Consequently, as the one or the other of these effects predominates or as they are equal, the temperature either rises, or sinks, or remains constant.

242. **Freezing mixtures.**—The absorption of heat in the passage of bodies from the solid to the liquid state has been used to produce artificial cold. This is effected by mixing together bodies which have an affinity for each other, and of which one at least is solid, such as water and a salt, ice and a salt, or an acid and a salt. Chemical affinity accelerates the fusion; the portion which melts robs the rest of the mixture of a large quantity of sensible heat, which thus becomes latent. In many cases a very considerable diminution of temperature is produced.

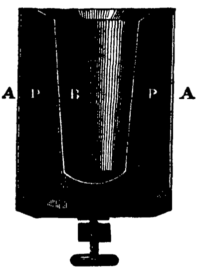


Fig. 220.

If the substances taken be themselves first previously cooled down, a still more considerable diminution of temperature is occasioned.

Freezing mixtures are frequently used in chemistry, in physics, and in domestic economy. The best effect is obtained when pretty large quantities, 2 or 3 pounds, of the mixture are used, and when they are intimately mixed. It is also advantageous to use the machines for a series of successive operations.

One form of the portable ice-making machines which have come into use of late years is represented in figure 220. In this ice is made by the great cold produced by the solution of nitrate of ammonia in water. In a metal cylinder, A, a hollow cone, B, of

thin metal plate is so fixed as to divide the interior of A into two parts; the cone B open at the top, and the ring-shaped space P surrounding it, and open at the bottom. The water to be frozen is placed in B to about $\frac{1}{8}$ its height; an india-rubber ring is placed on it, and then a wooden cover which can be screwed tightly down. B being thus closed, the space P is about half filled with ammonium nitrate, and water added until the space is nearly full. P having been closed by a similar cover to that of B, the whole apparatus is rotated for 8 or 10 minutes on its axis. There is then formed in B a hollow cone of transparent ice in the centre of which there is usually some water. Instead of placing water in B, mixtures of suitably flavoured creams and the like may be placed, and are frozen with equal facility.

The salt can be obtained again by evaporating the solution, and thus the process can be repeated over and over again with the same materials.

A mixture of sodium sulphate or Glauber's salt and hydrochloric acid produces also a great degree of cold; but, as a chemical decomposition takes place here, the mixture can only be used once. The greatest lowering of temperature is produced by taking two solids which by their mixture produce a liquid. Thus a mixture of 1 pound of common salt with 3 pounds of snow or coarsely powdered ice reduces the temperature to $-20°$ C.

One of the most useful materials for freezing mixtures is the crystallised chloride of calcium; when this is mixed with snow in the proportion of 10 parts of salt to 7 parts of snow a cold of $-50°$ C. is obtainable. By evaporating the solution thereby produced until the boiling point is 129°, and then allowing it to cool, stirring all the time, the salt is reproduced in the solid form in the state of a fine crystalline meal, which can again be used for fresh operations.

CHAPTER VII.

FORMATION OF VAPOURS. MEASUREMENT OF THEIR ELASTIC FORCE.

243. **Vapours.**—We have already seen (111) that *vapours* are the aëriform fluids into which substances, such as ether, alcohol, water, and mercury, are changed by the absorption of heat.

As regards the property of disengaging vapour, liquids are divided into two classes—*volatile* liquids, and *fixed* liquids. The first are those which have a tendency to pass into the state of vapour at the ordinary or even at lower temperatures ; such, for instance, are water, ether, chloroform, alcohol, which disappear more or less rapidly when exposed to the air in open vessels. To this class belongs a numerous family of liquids met with in nature, such as essence of turpentine, oil of lemons, of lavender, of thyme, of roses, etc., which are known as the *essential oils.*

Fixed liquids, on the contrary, are those which emit no vapour at any temperature ; such, for instance, are the *fatty oils*, as olive, rape, etc. When strongly heated, these oils are decomposed, and give rise to gaseous products ; but they do not emit vapours of the same nature as their own. There are some of them which are known as *drying oils*, that become thicker in the air, ; but this is in consequence of their having absorbed oxygen, and so undergone a chemical change, and not in consequence of evaporation.

Some substances form vapour even in the solid state. Ice is an instance of this, as is seen in dry cold winters, where the snow and ice quite disappear from the ground, without there having been any melting. Iodine, camphor, and odoriferous bodies in general, present the same phenomenon. Bodies which by the action of heat pass directly from the solid state to that of vapour are said to *sublime*, and this process is called *sublimation.*

The vapours of most colourless liquids are colourless also, and therefore invisible. What, in ordinary life, we speak of as steam or vapour—the breath from our mouth in winter, the cloud over boiling water, and the like—is no longer steam or vapour, but is

vapour which has been condensed into small spherules of liquid, and which then remains suspended in the air.

244. **Elastic force of vapour.**—Vapours formed on the surface of a liquid are disengaged in virtue of their elasticity; but this force is generally far lower than the pressure of the atmosphere, and hence liquids exposed to the air only evaporate slowly.

The following experiment renders evident the elastic force or *tension* of vapour. A bent glass tube has the shorter limb closed (fig. 221); this branch and part of the longer are filled with mercury. A drop of ether is then passed into the closed leg, which in virtue of its lower density rises to the top of the tube at B. The tube thus arranged is immersed in a vessel of water at a temperature of about 45°. The mercury then sinks slowly in the short branch, and the space AB is filled with a gas which has all the appearance of air. This gas or aeriform fluid is nothing but the vapour of ether, whose elastic force counterbalances not only the pressure of the column of mercury, CA, but also the atmospheric pressure exerted at C.

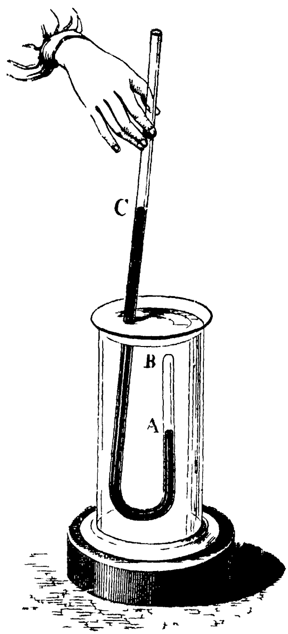


Fig. 221.

If the water in the vessel be cooled, or if the tube be withdrawn, the mercury gradually rises in the short leg, and the drop of liquid which seemed almost to have disappeared is re-formed. If, on the contrary, the water in which the tube is immersed be still more heated, the drop diminishes and the mercury descends further in the short leg; thus showing that fresh vapours are formed, and that the elastic force increases. This increase of tension with the temperature continues as long as any liquid remains to be vaporised.

The crackling of wood in fires is due to the increased tension of the vapours and gases formed in the pores of the wood during

combustion. In roasting chestnuts it is usual to slit the outer skin; the object of this is to allow the vapour formed to escape, for otherwise it would be liable to acquire such an elastic force as to burst the chestnut and scatter the particles far and wide.

245. **Formation of vapour in a vacuum.**—In the previous experiment the liquid changed very slowly into the state of vapour; the same is the case when a liquid is freely exposed to the air. In both cases the atmosphere is an obstacle to the vaporisation. In a vacuum there is no resistance, and the formation of vapours is instantaneous, as is seen in the following experiment. Four barometer tubes, filled with mercury, are immersed side by side in the same trough (fig. 222). One of them, A, serves as a barometer, that is, only contains dry mercury, and a few drops of water, alcohol, and ether are respectively introduced into the tubes, B, C, D. When the liquids reach the vacuum a depression of the mercury is at once produced. But this depression cannot be produced by the weight of the liquid, for it is but a very small fraction of the weight of the displaced mercury. Hence, in the case of each liquid, some vapour must have been formed whose elastic force has depressed the mercurial column, and as the depression is greater in the tube D than in the tube C, and greater in this than in the tube B, it is concluded that, for the same temperature, the elastic force of ether is greater than that of alcohol vapour, and that this in turn has a greater elastic force than that of water. If the depression be measured by means of a graduated scale it will be found that, at a tempera-

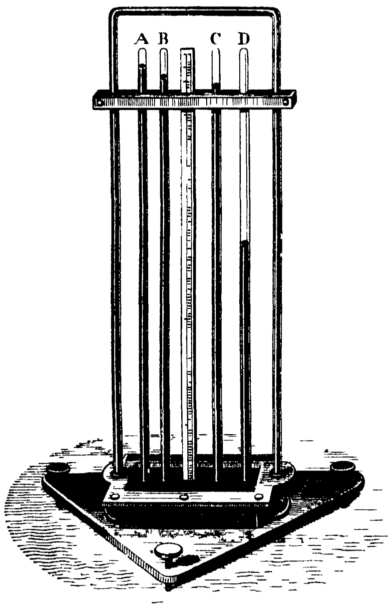


Fig 222

ture of 20°, the elastic force of ether is twenty-five times as great as that of water, and that of alcohol almost four times as great. From these experiments we obtain the two following laws for the formation of vapours :—

I. *In a vacuum all volatile liquids are at once converted into vapour.*

II. *At the same temperature the vapours of different liquids have different elastic forces.*

246. **Limit to the formation and to the pressure of vapour. Saturated space.**—The quantity of vapour which can be formed in a given space, whether at the ordinary or at higher temperatures, is always limited. For instance, in the above experiment, the depression of mercury in each tube, B, C, D, is not stopped for want of liquid which might form fresh vapour, for care is taken always to add so much that a slight excess remains unvaporised. Thus, in the tube D, enough ether is left ; yet we might wait weeks and years, and if the temperature did not increase, we should always see a portion of liquid in the tube, and the level of the mercury remain stationary. This shows that no new vapour can be formed in the tube, and at the same time that the elastic force of the vapour which is there cannot increase, which is expressed by saying that it has attained its *maximum tension.*

When a given space has acquired all the vapour which it can contain, it is said to be *saturated.* For instance, if in a bottle full of dry air a little water be placed, and the vessel be hermetically closed, part of the water will evaporate slowly, until the elastic force of the vapour formed holds in equilibrium the expansive force of that which still tends to form ; the formation of vapour then ceases, and the space is saturated.

247. **The quantity of vapour which saturates a given space is the same whether this is vacuous or contains air.**—For the same temperature the quantity of vapour necessary to saturate a given space is proportional to the elastic force, and is the same, whether the space is quite vacuous or contains air or any other gas. This may be shown by the experiment represented in fig. 223. A is a stout bottle which has been filled with dry air ; it is connected by means of a flexible india-rubber tube with a mercury manometer. In A is a thin glass bulb containing water or any more volatile liquid. When this is broken by shaking A, the liquid volatilises, and by its elastic force depresses the mercurial column. If the position of this column be read off before and after the experiment, the diffe-

rence measures the elastic force of the liquid, and this is found to be the same as if the experiment had been made with the same liquid in fig. 222. The difference between evaporation in air and in a vacuum is that in the former case the evaporation only takes place slowly, while in the second case it is instantaneous. Yet, for the same space, whether it be vacuous or full of air, the quantity of vapour formed which corresponds to the state of saturation varies with the temperature. The higher the temperature, the greater is the quantity of vapour contained in a given space, the denser it is therefore ; on the other hand, the lower the temperature, the less is the quantity required to saturate a given space.

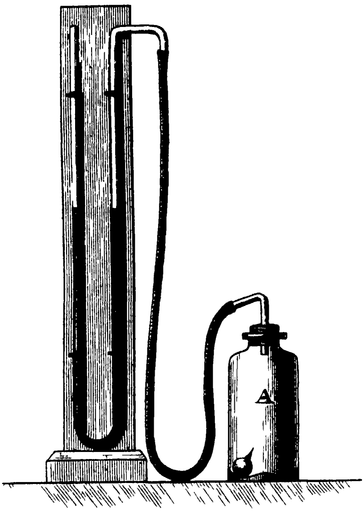


Fig. 223

The quantity of vapour present in air is very variable; but, spite of the abundant vaporisation produced on the surface of seas, lakes, and rivers, the air in the lower regions of the atmosphere is seldom quite saturated, even when it rains. This arises from the fact that aqueous vapour, being less dense than air, rises into the higher regions of the atmosphere, in proportion as it is formed, where, condensed by cooling, it falls as rain. During a dense fog the air is quite saturated.

248. **Evaporation. Causes which accelerate it.**—We have hitherto described, under the general term of *vaporisation*, all production of vapour, under whatever circumstances it takes place, whether slow or rapid, whether in air or in a vacuum ; while the term *evaporation* is especially assigned to the slow formation of vapour on the surface of a volatile liquid when it is exposed in the open air. It is in consequence of evaporation that the level of the water in a pond gradually sinks, and the pond ultimately dries up if it is not fed by a spring. Owing to the same cause the earth moistened by rain dries up and hardens, and wet linen exposed in

the air soon becomes dry. Several causes influence the rapidity of the evaporation of a liquid: its temperature; the quantity of the same vapour in the surrounding atmosphere; the renewal of this atmosphere; also the extent of the surface of the liquid.

Influence of temperature. Heat being the agent of all evaporation, the higher the temperature the more abundant is the formation of vapour. This property is utilised in the arts to hasten and complete the drying of a large number of products which are exposed in *stoves*—that is to say, in chambers, the temperature of which is kept at 30, 40, 60, and even 100 degrees, and the air of which is continually renewed to allow the vapour formed to escape.

Influence of pressure. We have already seen that the pressure of the atmosphere is an obstacle to the disengagement of vapour, and it will thus be understood that when this pressure is diminished vapour ought to be formed more abundantly. This, in point of fact, is what takes place whenever liquids are under a lower pressure than that of the atmosphere. In sugar refineries, in order to concentrate the syrups (that is, to reduce the volume by removing part of the water they contain), they are placed in large spherical vessels; and then, by the aid of large air-pumps of special construction, and worked by steam-engines, the air in the boilers is rarefied, which considerably accelerates the evaporation of water, and quickly brings the syrups to the wished-for degree of concentration.

The rate at which water evaporates may be investigated by means of the *evaporometer* (fig. 224). It consists of a graduated glass tube, a, closed at one end, 9 inches long and $\frac{3}{5}$ of an inch in diameter. It is filled with water, and closed at the bottom by a disc, o, of thick blotting paper; this is kept in its place by a brass ring which is pressed by a spring passing round the tube. The area of the disc is known, and, by observing the extent to which the level of the water has sunk during a certain interval of time, we have at once the means of calculating the volume of water which has evaporated during this time. The instrument is suspended in the open air in the shade, and near it is a wet bulb thermometer. At London the amount of water which evaporates in a year is represented by the height of a column of water of 2 feet.

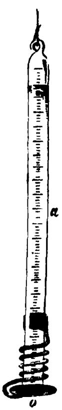


Fig. 224.

Influence of the renewal of air. In order to understand the influence of the third cause, it is to be observed that no evaporation could take place in a space already saturated

with vapour of the same liquid, and that evaporation would reach its maximum in air completely freed from this vapour. It therefore follows that, between these two extremes, the rapidity of evaporation varies according as the surrounding atmosphere is already more or less charged with the same vapour.

The effects of the renewal of this atmosphere is easily explained; for if the air or gas which surrounds the liquid is not renewed it soon becomes saturated, and evaporation ceases. Thus it is that the wind, removing the layers of air which are in contact with the earth, soon dries up the roads and streets. Hence, too, it is that linen hung out to dry does so far more rapidly on a windy than on a calm day.

Influence of the extent of surface. The greater the extent of surface which a liquid presents to the air, the more numerous are the points from which vapour is disengaged. Hence the evaporation of a liquid should be effected in vessels which are wide and shallow. This is what is done in the process of extracting salt from sea water in *salt gardens.* The sea water is admitted into broad and shallow pits excavated in the ground. Under the influence of the sun's heat the water evaporates slowly, and when the concentration has reached the point at which the liquid is saturated, the salt begins to form on the surface and is raked off.

249. **Ebullition.**—*Ebullition*, or *boiling*, is the rapid production of elastic bubbles of vapour within the mass of a liquid itself.

When a liquid, water for example, is heated at the lower part of a vessel, the first bubbles are due to the disengagement of air which had previously been absorbed. Small bubbles of vapour then begin to rise from the heated parts of the sides, but as they pass through the upper layers, the temperature of which is lower, they condense before reaching the surface. The formation and successive condensation of these first bubbles occasion the *singing* noticed in liquids before they begin to boil. Lastly, large bubbles rise through the liquid and burst on the surface, and this constitutes the phenomenon of ebullition (fig. 225).

250. **Laws of ebullition.**—The laws of ebullition have been determined experimentally, and are as follows:—

I. *The temperature of ebullition, or the boiling point, increases with the pressure.*

II. *For a given pressure, boiling commences at a certain temperature, which varies in different liquids, but which for equal pressures is always the same in the same liquid.*

III. ***Whatever be the temperature of the source of heat, as soon as ebullition begins, the temperature of the liquid remains stationary.***

Thus, the boiling point of water under the ordinary atmospheric pressure being 100°, it could not be heated beyond that point, whatever the intensity of the source of heat; the only effect of higher temperature being to hasten the rapidity of vaporisation; hence all the heat which passes from the source into the liquid is absorbed by the vapour disengaged. But, as this vapour is itself at 100°, we must conclude that this heat is not absorbed to raise the temperature of the vapour, but *simply to produce it*; that is, to change the substance from the liquid into the gaseous state, a phenomenon analogous to that which fusion presents (238). This disappearance of heat during ebullition will be subsequently investigated under the name of latent heat of vaporisation (255).

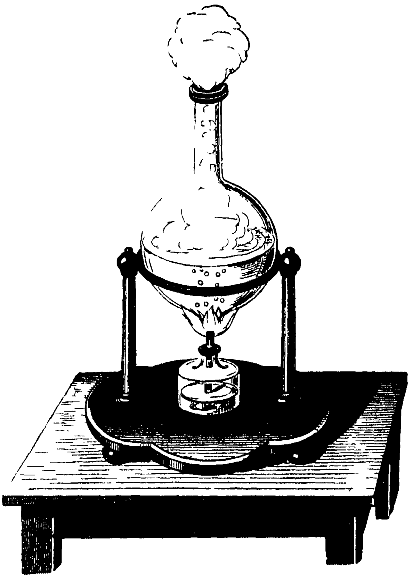


Fig 225.

Boiling points under the pressure of an atmosphere.

Sulphurous acid	– 10°	Turpentine	160°
Ether	37	Strong sulphuric acid	325
Bisulphide of carbon	48	Mercury	350
Bromine	63	Sulphur	447
Alcohol	78	Cadmium	860
Distilled water	100	Zinc	1040

251. **Causes which influence the boiling point.**—The boiling point of a liquid is affected by the presence of substances in solution, by the degree of pressure to which it is subjected, and by the nature of the vessels in which the boiling takes place.

The boiling of a liquid is the more retarded the greater the quantity of any substance it may contain in solution, provided that the substance be not volatile, or, at all events, be less volatile than the liquid itself. Water, which boils at 100° when pure, boils at 109° when it is *saturated* with common salt: that is, when it has taken up as much of this salt as it can dissolve.

Influence of pressure. The degree of pressure to which a liquid is subjected has the most important influence on its boiling point.

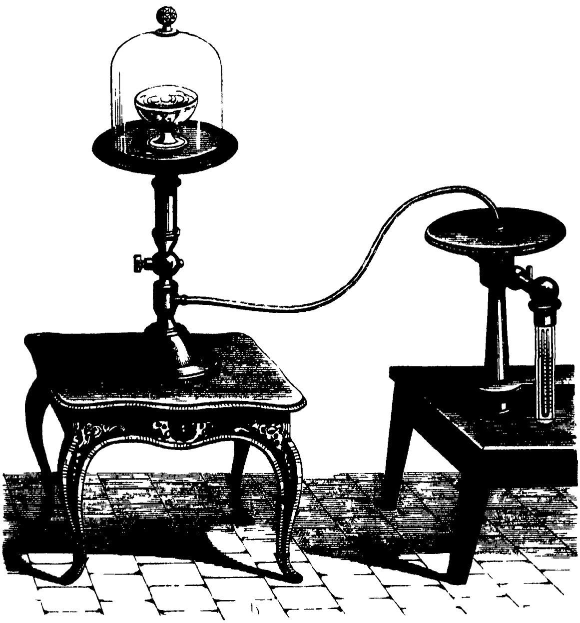


Fig. 226.

The greater the external pressure the greater must be the tension in order that the vapour may be disengaged, and therefore the higher the temperature. On the contrary, the less the pressure, the lower the temperature at which ebullition takes place. If the pressure of the atmosphere be removed, water may be made to boil, even at the ordinary temperature. The experiment may be arranged in the

manner represented in fig. 226. A glass cup containing water is placed under the bell-jar of an air-pump, or, in order that the experiment may be seen by a number of spectators, the bell is placed on a movable plate connected with the pump by a tube. When a vacuum is produced, or when the air is very rarefied, the water is seen to boil, evidently indicating a considerable disengagement of vapour. Yet the temperature of the liquid is not raised ; the boiling is, on the contrary, a source of cold, owing to the heat which becomes latent in the formation of vapour.

The influence of pressure on boiling may further be illustrated by means of an experiment of Franklin's. The apparatus consists of a bulb and a tube, joined by a tube of smaller dimensions (fig. 227). The tube is drawn out and the apparatus filled with water, which is then in great part boiled away by means of a spirit-lamp. When it has been boiled long enough to expel all the air, the tube

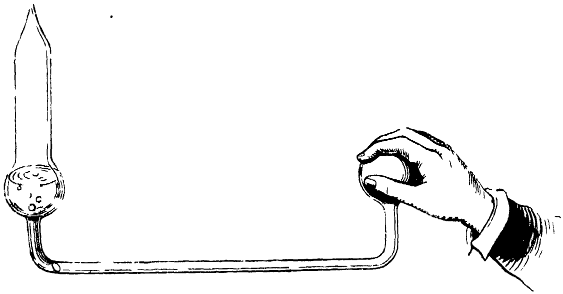


Fig. 227.

is sealed as in the construction of the water hammer (53). There is then a vacuum in the apparatus, or rather there is only a pressure due to the tension of aqueous vapour, which at ordinary temperatures is very small. Consequently, if the bulb be placed in the hand, as shown in the figure, the heat is sufficient to produce a pressure, which drives the water into the tube and causes a brisk ebullition.

A paradoxical but very simple experiment also well illustrates the dependence of the boiling point on the pressure. Water is boiled for some time in a glass flask, and when all air has been expelled by the steam the flask is closed by a cork and inverted as shown in fig. 228. If the bottom is then cooled by a stream of cold water from a sponge, the water begins to boil again. This

arises from the condensation of the steam above the surface of the water, by which a partial vacuum is produced.

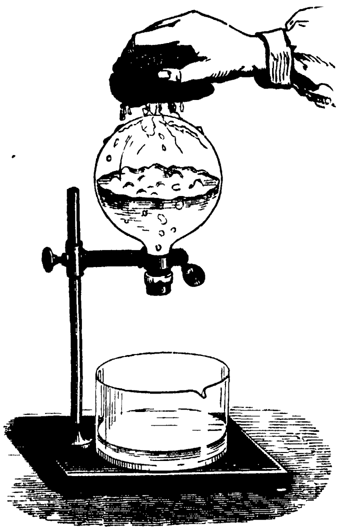


Fig. 228.

As the pressure of air diminishes in proportion as we rise in the atmosphere, it will be seen, from what has been said, that on high mountains water must boil at lower temperatures than at the sea level. This, in fact, is the case. On Mont Blanc, at a height of 15,800 feet, water boils at 84°; at Quito, at a height of 11,000 feet, at 90°; and at Madrid, the height of which is 3,000 feet, it boils at 97°. This diminution in the temperature of ebullition at great heights is a material obstacle to the preparation of food, for at the temperature of 90° the extraction of the nourishment and of the flavour is far more imperfect than under the usual conditions.

In deep mines, on the contrary, such as those of Cornwall and of Lancashire, the reverse is the case: the pressure increases with the depth, and the boiling point is higher than at 100°.

Influence of the nature of the vessel on the boiling point. Gay-Lussac observed that water in a glass vessel required a higher temperature for ebullition than in a metal one. Taking the temperature of boiling water in a copper vessel at 100°, its boiling point in a glass vessel was found to be 101°; and if the glass vessel had been previously cleaned by means of sulphuric acid and of potass, the temperature would rise to 105° or even 106° before ebullition commenced. Whatever be the boiling point of water, the temperature of its vapour is uninfluenced by the material of which the vessels are made.

252. **Papin's digester.**—What has hitherto been said in reference to the formation of vapour has applied to the case of liquids heated in open vessels. Ebullition can only take place under these

conditions; for in a closed vessel, since the vapour cannot escape into the atmosphere, its elastic force and density continually increase, but that peculiarly rapid disengagement of vapour which constitutes boiling is impossible. There is, moreover, this difference between heating in an open and in a closed vessel; that, in the former case, the temperature can never exceed that of ebullition, while in a closed vessel it may be raised, so to speak, to an indefinite extent. Thus we have seen (251) that in an open vessel water cannot be heated beyond 100° C., all the heat imparted to it being absorbed by the vapours disengaged. But as this disengagement of vapour cannot take place in a closed vessel, water and the vapour may be raised to a far higher temperature than 100°. This, however, is not unattended with danger, from the very high pressure which the vapour then acquires.

Figure 229 represents the apparatus used in physical lectures for the purpose of heating water in a closed vessel beyond 100 degrees. It is known as *Papin's digester*. In consists of a cylindrical bronze vessel, M (fig. 229), provided with a cover, which is firmly fastened down by a screw. In order to close the vessel hermetically, sheet lead is placed between the edges of the cover and the vessel. At the bottom of a cylindrical cavity, which traverses a cylinder and tubulure, the cover is perforated by a small orifice in which there is a rod, *u*. This rod presses against a lever, *ab*, movable at *a*, and the pressure may be regulated by means of a weight, *p*, movable on this lever. The lever is so weighted

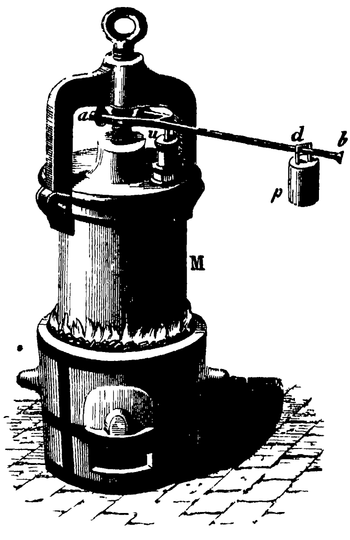


Fig. 229.

that when the pressure in the interior is equal to six atmospheres, for example, the valve rises and the vapour escapes. The destruction of the apparatus is thus avoided, and the mechanism, which will be described in speaking of the steam-engine (273), has

hence received the name of *safety-valve.* The digester is filled about two-thirds with water, and is heated on a furnace. The water may thus be raised to a temperature far above 100°, and the tension of the vapour increased to several atmospheres according to the weight on the lever.

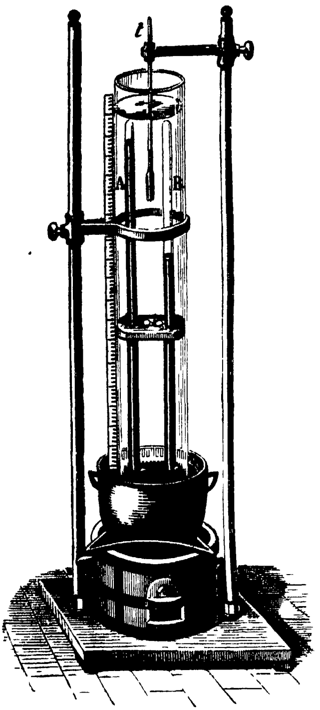


Fig. 230.

The apparatus has received the name *digester*, from a Latin word signifying to dissolve, for the high temperature which water can acquire greatly increases its solvent power. Thus it is used to extract from bones the substance known as *glue*, which could not be accomplished at 100° C.

From the enormous elastic force which vapour may acquire when heated in a closed vessel, it will be understood how important it is not to close tightly the vessel in which water is contained for domestic purposes. Thus a hot water-bottle for heating the feet of invalids should be uncorked before being placed near the fire ; for it might burst, or at any rate the cork might be driven out, and a more or less serious accident be caused. In like manner, when a locomotive stops, the steam must be allowed to escape ; for otherwise, as it is continually being formed in the boiler without any being consumed in working the engine, it might ultimately acquire such an elastic force that an explosion would ensue.

253. **Measurement of the elastic force of aqueous vapour.**— The important applications which have been made of the elastic force of aqueous vapour have led philosophers to measure with care the intensity of this force at various temperatures.

Dalton first measured the elastic force of aqueous vapour for temperatures between 0° and 100° by means of the apparatus repre-

sented in fig. 230. Two barometer tubes, A and B, are filled with mercury, and inverted in an iron bath full of mercury, and placed on a furnace. The tube A is an ordinary barometer tube, freed from air and moisture; but into the tube B is introduced a small quantity of water. The tubes are supported in a cylindrical vessel full of water, the temperature of which is indicated by the thermometer *t*. The bath being gradually heated, the water in the cylinder becomes heated too; the water which is in the tube B vaporises, and in proportion as the elastic force of its vapour increases. the mercury sinks. The depressions of the mercury corresponding to each degree of the thermometer are indicated on the scale. Thus if, when the thermometer is at 70°, the mercury is 233 millimetres lower in the tube B than in the tube A, this shows that at 70° the tension of aqueous vapour is 233 millimetres; which amounts to saying that it exercises on the sides of the vessel which contains it a pressure equal to the weight of a column of mercury 233 millimetres in height.

By noting in the above manner the depression in the barometer B, as compared with A, Dalton determined the elastic force of aqueous vapour from 0° to 100°. He found it to be 760 millimetres, or 29·92 inches: that is to say, one atmosphere (121).

Dulong and Arago determined the elastic force of aqueous vapour above 100° up to pressures of 24 atmospheres. More recently Regnault measured the elastic force of aqueous vapour both above and below 100°: and from the researches of this experimenter the following table has been taken, in which the elastic forces at various temperatures are respectively measured by the height in millimetres of the column of mercury which they can balance.

Elastic force or tension of aqueous vapour.

Temperature	Tension in millimetres	Temperature	Tension in millimetres
0	4·60	60	148·79
5	6·53	70	233·09
10	9·17	80	354·64
15	12·70	90	525·45
20	17·39	100	760·00
30	31·55	101	787·63
40	54·91	120	1520·00
50	91·98	160	4580·00

This table shows that the elastic force of aqueous vapour increases far more rapidly than the temperature. Thus at 50° the tension is only 91·9 millimetres; while at 100 degrees, that is to say, double the temperature, the tension is eight times as great.

254. **Measurement of heights by the boiling point.**—From the connection between the boiling point of water and the pressure, the heights of mountains may be measured by the thermometer instead of by the barometer. Suppose, for example, it is found that water boils on the summit of a mountain at 90°, and at its base at 98°; at these temperatures the elastic force or tension of the vapour is equal to that of the pressure on the liquid—that is, to the pressure of the atmosphere at the two places respectively. Now the tensions of aqueous vapour for various temperatures have been determined, and accordingly the tensions corresponding to the above temperatures are sought in the tables. These numbers represent the atmospheric pressures at the two places: in other words, they give the barometric heights, and from these the height of the mountain may be calculated by the method already given (132). An ascent of about 1,080 feet produces a lowering of 1° C. in the boiling point, or, what is the same thing, an ascent of 600 feet produces a lowering of 1° F.

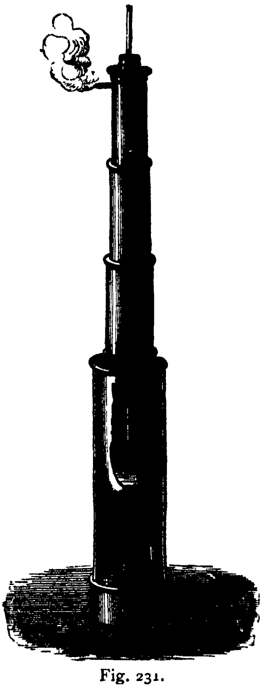


Fig. 231.

The instruments used for this purpose are called *thermobarometers* or *hypsometers*, and were first applied by Wollaston. They consist essentially of a small metal vessel provided with a spirit lamp, for boiling water (fig. 231). To this is fitted a long tube, the parts of which slide in each other like a telescope, so that it can be shut up for convenience in transport. By means of a cork a delicate thermometer fits in the top of the tube, so that the bulb and nearly the whole of the stem are surrounded by the steam. When the thread of mercury is stationary its position is

read oft. The graduation of the thermometer is only from 80° or 90° to 100°; so that each degree occupying a considerable space on the scale, the 10ths, and even the 100ths, of a degree may be estimated, and thus it is possible to determine the height of a place by means of the boiling point to within about 10 feet.

255. **Latent heat of vapour.**—In speaking of ebullition we have seen that, from the moment a liquid begins to boil, its temperature ceases to rise whatever be the intensity of the source of heat. It follows that a considerable quantity of heat becomes absorbed in ebullition, the only effect of which is to transform the body from the liquid to the gaseous condition. And conversely, when a saturated vapour passes into the state of liquid, it gives out that amount of heat which it had absorbed in becoming converted into vapour.

Thus, if we mix a pound of water at 100° with six pounds of water at 0°, the temperature of the mixture will be a little over 14°; but if a pound of steam at 100° be passed into six pounds of water at zero, the temperature of the mixture will be about 91°.

These phenomena were first observed by Black, and he described them by saying that during vaporisation a quantity of sensible heat became latent, and that the latent heat again became free during condensation. The quantity of heat which a liquid must absorb in passing from the liquid to the gaseous state, and which it gives out in passing from the state of vapour to that of liquid, is spoken of as the *latent heat of evaporation.*

The analogy of these phenomena to those of fusion will be at once seen. The modes of determining them need not be described here; but we may give the following results which have been obtained for the latent heats of evaporation of a few liquids :—

Water . . .	540	Bisulphide of carbon .	87
Alcohol. . .	208	Turpentine. . .	74
Ether . . .	90	Bromine . . .	46

The meaning of these numbers is—in the case of water, for instance—that it requires as much heat to convert a pound of water from the state of liquid, at the boiling point, to that of vapour at the same temperature, as would raise a pound of water through 540 degrees, or 540 pounds of water through one degree; or that the conversion of one pound of vapour of alcohol at 78° into liquid alcohol of the same temperature would heat 208 pounds of water through *one* degree.

It has here been assumed that the boiling is under the ordinary

pressure of the atmosphere; if the pressure is lower and therefore the boiling point lower the value for the latent heat is greater. Watt supposed that the sum of the latent and sensible heats was a constant quantity, and equal to 640; thus, if water were boiled at 90°, its latent heat on this view would be 550°. This is not, however, the case; the total heat of vaporisation is expressed by a constant number 606·5 added to the product of 0·305 into the temperature of boiling on the centigrade scale.

256. **Cold due to evaporation.**—Whatever, then, be the temperature at which a vapour is produced, an absorption of heat always takes place. If, therefore, a liquid evaporates, and does not receive from without a quantity of heat equal to that which is expended in producing the vapour, its temperature sinks, and the cooling is greater in proportion as the evaporation is more rapid.

This may become a source of very great cooling. Thus if a few drops of ether be placed on the hand, and this be agitated to accelerate the evaporation, great cold is experienced. By delivering the ether in the form of spray the cold is still greater, and on this depends the method of obtaining local anæsthesia. With liquids which are less volatile than ether, like alcohol and water, the same phenomenon is produced, but the cooling is less marked.

On coming out of a bath, and more especially in the open air and with some wind, a very sharp cold is experienced, due to the vapour formed on the surface of the body. Moist linen is cold and injurious, because it withdraws from the body the heat which the moisture requires for conversion into vapour.

The cooling effect produced by a wind or draught does not necessarily arise from the wind being cooler, for it may, as shown by the thermometer, be actually warmer, but arises from the rapid evaporation it causes from the surface of the skin. We have the feeling of oppression, even at moderate temperatures, when we are in an atmosphere saturated by moisture in which no evaporation takes place.

The cooling produced by the use of fans is due to the increased evaporation they produce. The freshness occasioned by watering the streets is also an effect of evaporation.

The cold produced by evaporation is used in hot climates to cool water by means of *alcarrazas*. These are porous earthen vessels, through which water percolates, so that on the outside there is a continual evaporation, which is accelerated when the vessels are placed in a current of air. For the same reason wine is cooled

by wrapping the bottles in wet cloths and placing them in a draught.

257. **Water and mercury frozen in a vacuum.**—From the great quantity of heat which disappears whenever a liquid is converted into vapour, it will be seen that by accelerating the evaporation we have a means of producing cold. We have found that liquids vaporise more rapidly the lower the pressure (251). Hence, if a vessel containing water be placed in a space from which the air is exhausted, it should cool very rapidly.

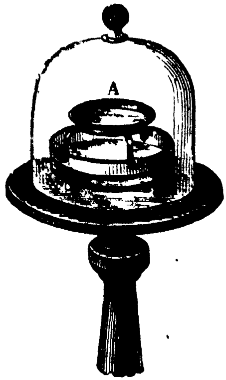


Fig 232.

Leslie succeeded in freezing water by means of rapid evaporation. Under the receiver of the air-pump is placed a vessel containing strong sulphuric acid, a substance which has a great affinity for water, and above it a thin, shallow, porous capsule A (fig. 232), containing a small quantity of water. By exhausting the receiver the water begins to boil, and, since the vapours are absorbed by the sulphuric acid as fast as they are formed, a rapid evaporisation is produced, which quickly effects the freezing of the water.

By using liquids more volatile than water, more particularly liquid sulphurous acid, which boils at $-10°$, a degree of cold is obtained sufficiently intense to freeze mercury. The experiment may be made by covering the bulb of a thermometer with cotton wool, and, after having moistened it with liquid sulphurous acid, placing it under the receiver of the air-pump. When a vacuum is produced the mercury is quickly frozen.

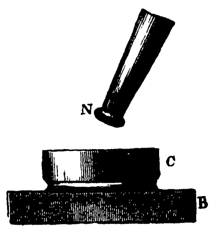


Fig. 233.

By passing a current of air, previously cooled, through liquid chloride of methyle, temperatures of from $-23°$ to $-70°$ C. may be maintained with great constancy for several hours.

Thilorier, by directing a jet of liquid carbonic acid on the bulb of an alcohol thermometer, obtained a cold of $-100°$ without freezing the alcohol. With a mixture of solid carbonic acid, liquid protoxide of nitrogen and ether, Despretz obtained a sufficient degree of cold to reduce alcohol to the viscous state.

By means of the evaporation of bisulphide of carbon the formation of ice may be illustrated (fig. 233) without the aid of an air-pump. A little water is dropped on a small piece of wood, B, and a capsule of thin copper foil, C, containing bisulphide of carbon, is placed on the water. The evaporation of the bisulphide is accelerated by means of a pair of bellows, and after a few minutes the water freezes round the capsule, so that the latter adheres to the wood.

In like manner, if some water be placed in a test tube, which is then dipped in a glass containing some ether, and a current of air be blown through the ether by means of a glass tube fitted to the nozzle of a pair of bellows, the rapid evaporation of the ether very soon freezes the water in the tube.

In the East Indies ice is formed even at a temperature of 8° to 10° C. provided the nights are clear and bright. For this purpose water is exposed in flat porous vessels, which are placed in shallow pits lined with bad conductors such as straw. The water percolates through the porous vessel, and, there evaporating, withdraws so much heat from the vessel and from the rest of the water that it freezes.

This process is favoured by the absence of aqueous vapour; for this has a great absorptive power for the obscure heat radiated from the earth (218), and thus obstructs it in its attempt to escape.

CHAPTER VIII.

LIQUEFACTION OF VAPOURS AND GASES.

258. **Liquefaction of vapours.**—The *liquefaction* or *condensation* of vapours is their passage from the aeriform to the liquid state. Condensation may be due to three causes—*cooling*, *compresssion*, or *chemical affinity*.

When vapours are condensed, their latent heat becomes free —that is, it affects the thermometer. This is readily seen when a current of steam at 100° is passed into a vessel of water at the ordinary temperature. The liquid becomes rapidly heated, and soon reaches 100°. The quantity of heat given up in liquefaction is equal to the quantity absorbed in producing the vapour.

Liquefaction by chemical affinity. The affinity of certain substances for water is so great as to condense the vapours in the atmosphere, even when they are far from their point of saturation. Thus, when highly hygroscopic substances, such as quicklime, potass, or sulphuric acid, are exposed in the air, they always absorb aqueous vapour. Certain varieties of common salt exposed to the air absorb and condense so much aqueous vapour as to become liquid. Many other salts have the same property, and are hence called *deliquescent salts*.

Liquefaction by pressure. Let us suppose a vessel containing aqueous vapour, a cylinder for instance, and in this cylinder a piston which can be depressed at will, like that represented in fig. 4, page 10. When the piston is depressed, the vapour behaves like a true gas, as it is not at first in a state of saturation, the pressure increasing its elastic force and density without liquefying it. But the more the piston is depressed, the smaller does the volume of the vapour become, and a point is ultimately reached at which the vapour present is just sufficient to saturate the space. From this point the slightest increase of pressure causes a portion of vapour to pass into the liquid state, and the liquefaction continues as long as the excess of pressure lasts; so that if the piston descends to the bottom of the cylinder all the vapour is condensed. In this

experiment it is to be observed that when once saturation is attained, provided there is no air in the cylinder, the resistance to the depression of the piston does not increase in proportion as it descends, which arises from the condensation of the vapour, and, confirms what was previously said (247) as to the maximum tension of vapour in a state of saturation.

Liquefaction by cooling. Cooling, as well as pressure, only causes vapours to liquefy when they are in a state of saturation. But when once a given space is saturated, the slightest lowering of temperature takes from the vapours the heat which gives them their condition, the attraction between the molecules preponderates, they agglomerate, forming extremely small droplets, which float in the air and are deposited on the surrounding bodies.

Vapours are ordinarily condensed by cooling. Thus the vapours exhaled from the nose and mouth of animals first saturate the colder air in which they are disengaged, and they then condense with a cloud-like appearance. Owing to the same phenomenon the vapours become visible which are disengaged from boiling water, those which rise from chimneys, the fogs formed above rivers, and so forth. All these vapours appear more distinctly in winter than in summer, for then the air is colder, and the condensation is more complete.

In cold weather, the windows in heated rooms are seen to become covered with dew on the inside. The air of these rooms is in general far from being saturated with vapour, but the layers of air in immediate contact with the windows become colder ; and as the quantity of vapour necessary to saturate a given space is less the colder the space, a moment is reached at which the air in contact with the windows is saturated, and then the vapour it contains is quickly deposited. In a time of thaw, when the air is hotter on the outside than on the inside, the deposit is formed on the outside. To the same cause is due the deposit of moisture formed on walls which is expressed by saying that they *sweat* ; an unsuitable expression, for the moisture does not come from the walls but from the atmosphere. The walls are colder than the air, and they lower the temperature of the layers in contact with them, and condense the vapours. A similar effect is produced when in summer a bottle of wine is brought from the cellar, or when a glass is filled with cold water ; a deposit of dew is formed on the surface of these vessels. The same phenomenon does not occur so often in winter, for then the temperature of the atmosphere being frequently the

same as that of the bottle, or even lower, the layers of air in immediate contact with it are not cooled.

259. **Heat disengaged during condensation.**—It has been seen that any liquid in vaporising absorbs a quantity of heat. This heat is not destroyed, for in the converse change it reappears in the *sensible* state : that is to say, it is capable of acting on our sense of feeling and on the thermometer. For instance, we know that a pound of water absorbs in vaporising 540 units of heat (255); that is to say, a quantity of heat necessary to raise 540 pounds of water from 0° to 1° ; conversely, a pound of steam at 100°, which is liquefied and gives a pound of water at 100°, causes 540 units to

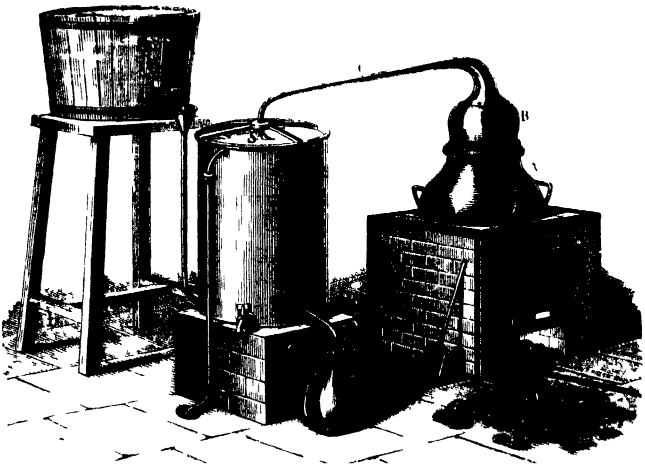


Fig. 234

pass from the latent to the sensible state, an amount of heat which is utilised in heating by steam. This amount is equal to that which would be capable of raising 4 pounds of cast iron to its melting point.

The quantity of heat which becomes free when aqueous vapour is condensed is sometimes utilised for heating private houses, hot-houses, and public buildings. Steam is produced in boilers like those used in steam-engines, and passes from thence into metal tubes concealed behind the wainscot, or into columns which serve at the same time as ornaments for rooms. The steam condensing

in these tubes gives up a considerable quantity of heat, which they impart to the surrounding air.

260. **Distillation. Stills.**—*Distillation* is an operation by which volatile liquid may be separated from substances which it holds in solution, or by which two liquids of different volatilities may be separated. The operation depends on the transformation of liquids into vapours by the action of heat, and on the condensation of these vapours by cooling.

The apparatus used in distillation is called a *still*. Its form may vary greatly, but it consists essentially of three parts : 1st, the *body*, A (fig. 234), a copper vessel containing the liquid, the lowest part of which fits in the furnace ; 2nd, the *head*, B, which fits on the body, and from which a lateral tube, C, leads to, 3rd, the *worm*, S, a long spiral tin or copper tube, placed in a cistern kept constantly full of cold water. The object of the worm is to condense the vapour, by exposing a great extent of cold surface.

To free ordinary water from the many impurities which it often contains, it is placed in a still and heated. The vapour disengaged is condensed in the worm, and the distilled water arising from the condensation is collected in the receiver, D. The vapour, in condensing, rapidly heats the water in the cistern, which must, therefore, be constantly renewed. For this purpose a continual supply of cold water passes into the bottom of the cistern, while the heated, and therefore lighter, water rises to the surface, and escapes by a tube in the top of the cistern.

Brandy is obtained from wine by means of distillation. Wine consists essentially of water, alcohol, and colouring matter ; when heated in a still to a temperature between 78° and 100°, the alcohol, which boils at 78°, vaporises, while water, which only boils at 100°, remains behind, or at all events only passes over in a small quantity. The liquid which passes over in this distillation is brandy, which is in effect dilute alcohol.

261. **Apparatus for determining the alcoholic value of wines.**—One of the forms of this apparatus consists of a glass flask resting on a tripod, and heated by a spirit lamp (fig. 235). By means of a caoutchouc tube this is connected with a worm placed in a copper vessel filled with cold water, and below which is a test-glass for collecting the distillate. On this are three divisions, one *a*, which measures the quantity of wine taken ; the two others indicating one-half and one-third of this volume.

The test-glass is filled with wine up to *a* ; this is then poured

into the flask, which having been connected with the worm, the distillation is commenced. The liquid which distils over is a mixture of alcohol and water ; for ordinary wines, such as claret and hocks, about one-third is distilled over, and for wines richer in spirit, such as sherries and ports, one-half must be distilled : experiment has shown that under these circumstances all the alcohol passes over in the distillate. The measure is then filled up with distilled water to *a* ; this gives the mixture of alcohol and water of the same volume as the wine taken, free from all solid matters, such as sugar, colouring matter, and acid, but containing all the alcohol. The specific gravity of this distillate is then taken by means of an alcoholometer (109), and the number thus obtained corresponds to a certain strength of alcohol as indicated by the tables.

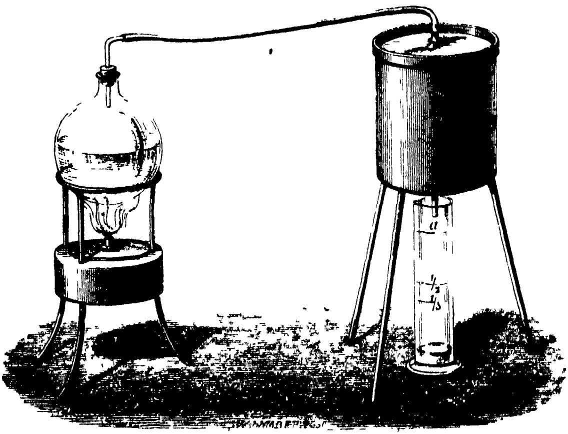


Fig. 235.

262. **Liquefaction of gases.**—We have already seen (258) that a saturated vapour, the temperature of which is constant, is liquefied by increasing the pressure, and that, the pressure remaining constant, it is brought into the liquid state by lowering the temperature.

Unsaturated vapours behave in all respects like gases. And it is natural to suppose that what are ordinarily called *permanent gases* are really unsaturated vapours. For the gaseous form is accidental, and is not inherent in the nature of the substance. At ordinary temperatures sulphurous acid is a gas, while in countries

near the Poles it is a liquid; in temperate climates ether is a liquid, at a tropical heat it is a gas. And just as unsaturated vapours may be brought to the state of saturation, and be then liquefied, by suitably diminishing the temperature or increasing the pressure, so, by the same means, gases may be liquefied. But, as they are mostly very far removed from this state of saturation, great cold and pressure are required. Some of them may, indeed, be liquefied either by cold or by pressure; for the majority, however, both processes must be simultaneously employed. No gases can resist these combined actions, and those which for long resisted all

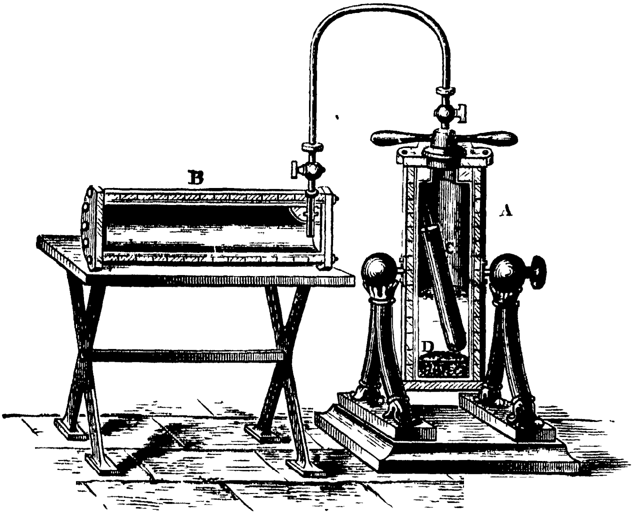


Fig. 236.

attempts to liquefy them, hydrogen, oxygen, nitrogen, binoxide of nitrogen, and carbonic oxide, become liquid when submitted to a sufficient degree of cold and pressure. In the case of oxygen the temperature is – 130° C., and the pressure 470 atmospheres.

One of the most remarkable of the early experiments on the liquefaction of gases is that made by Thilorier to liquefy and solidify carbonic acid. The principle of the method was first devised and applied by Faraday. The apparatus used by Thilorier consists of two cast-iron cylinders with very thick sides, of 5 to 6 quarts

capacity (fig. 236). They are hermetically closed, and are connected by means of a leaden tube. In one of these cylinders, A, called the *generator*, are placed the substances by whose chemical action carbonic acid is evolved. These are ordinarily bicarbonate of sodium, D, and sulphuric acid in the tube C. The second cylinder, called the *receiver*, B, is empty; and the gas disengaged by the chemical action in the generator distils over, and, as the receiver is colder, it condenses in virtue of its increasing pressure. As much as two quarts of liquid carbonic acid have thus been prepared.

At a temperature of 15 degrees the tension of the compressed gas in the cylinders is not less than 50 atmospheres; a pressure which would burst the vessels if they were not solidly constructed. An accident of this kind happened some years ago, and caused the death of Thilorier's assistant.

To obtain solid carbonic acid, the receiver is provided with a stopcock attached to a tube, which dips in the liquid acid. On opening this stopcock the liquid acid driven by pressure jets out; passing then from a tension of 50 atmospheres down to a single one, a part of the liquid volatilises; and, in consequence of the heat absorbed by this evaporation, the rest is so much cooled as to solidify in white flakes like snow or anhydrous phosphoric acid.

Solid carbonic acid evaporates very slowly. By means of an alcohol thermometer its temperature has been found to be about $-90°$. A small quantity placed on the hand does not produce the sensation of such great cold as might be expected. This arises from the imperfect contact. But if the solid be mixed with ether the cold produced is so intense that when a little is placed on the skin all the effects of a severe burn are produced. A mixture of these two substances solidifies four times its weight of mercury in a few minutes. When a tube containing liquid carbonic acid is placed in this mixture the liquid becomes solid, and looks like a transparent piece of ice.

CHAPTER IX.

SPECIFIC HEAT. CALORIMETRY.

263. **Calorimetry. Thermal unit.**—The object of calorimetry is to measure the *quantity of heat* which a body parts with or absorbs when its temperature sinks or rises through a certain number of degrees, or when it changes its condition.

We must distinguish between quantity of heat and temperature (202); the temperature of a red-hot iron poker will be considerably higher than that of a bucket of warm water, but the quantity in the latter case will be greater. Quantities of heat may be expressed by any of its effects which can be directly measured, but the most convenient is the alteration of temperature; and quantities of heat are usually defined by stating the extent to which they are capable of raising the temperature of a known weight of a substance, such as water.

The unit chosen for comparison, and called the *thermal unit*, is not everywhere the same. In France it is the quantity of heat standard necessary to raise the temperature of *one* kilogramme of water through *one* degree Centigrade; this is called the *calorie*. In this book we shall adopt, as a thermal unit, *the quantity of heat necessary to raise one pound of water through one degree Centigrade*; 1 *calorie* = 2·2 thermal units, and 1 thermal unit = 0·45 *calorie*.

264. **Specific heat.**—When equal weights of two different substances at the same temperature—mercury and water, for example—are placed in similar vessels and subjected for the same length of time to the heat of the same lamp, or are placed at the same distance in front of the same fire, it is found that after a time their temperatures will differ considerably; the mercury will be much hotter than the water. But as, from the conditions of the experiment, they have, during all this time, been each receiving the same amount of heat, it is clear that the quantity of heat which is sufficient to raise the temperature of mercury through a certain number of degrees will only raise the temperature of the same quantity of

water through a less number of degrees; in other words, that it requires more heat to raise the temperature of water through one degree than it does to raise the temperature of mercury by the same extent. Conversely, if the same quantities of water and of mercury at 100° C. be allowed to cool down to the temperature of the atmosphere, the water will require a much longer time for this purpose than the mercury; hence in cooling through the same number of degrees, water gives out more heat than does mercury.

If a pound of water at 100° is mixed with a pound of water at zero, the mixture has a temperature of 50°. But if a pound of mercury at 100° is mixed with a pound of water at zero, the temperature of the mixture will only be about 3°. That is to say, while the mercury has cooled through 97°, the temperature of the water has only been raised 3°. Consequently, for the same weight, water requires about 32 times as much heat as mercury does to produce the same rise of temperature.

Again, if a pound of water at 10° be shaken with a pound of turpentine at 60°, the temperature of the mixture will be about 24°. So that the heat which turpentine gives out in sinking through 36 degrees will only raise the temperature of an equal weight of water through 14 degrees; or, in other words, the heat required to raise turpentine through a certain range of temperature is only about two-fifths of that required to raise water through the same temperature.

If similar experiments are made with other substances, it will be found that the quantity of heat required to effect a certain change of temperature is different for almost every substance; and we speak of the *specific heat* or *calorific capacity* of a body as the quantity of heat which it absorbs when its temperature rises through a given range of temperature, from zero to 1° for example, compared with the quantity of heat which could be absorbed under the same circumstances by the same weight of water. In other words, water is taken as the standard for the comparison of specific heats. Thus, to say that the specific heat of silver is 0·057 means that the weight of heat which would raise the temperature of any given weight of silver through 1° C. would only raise the temperature of the same quantity of water through 0·057° C., or that the quantity of heat which would raise a given weight of water through 1° C. would raise the same weight of silver through 19·5 C.

The specific heat of water being unity, that of air is 0·237 if we compare *equal weights* of the two substances. Hence a pound of water in losing one degree of temperature would raise the tem-

perature of 4·2 pounds of air through one degree. But as water is 770 *times* as *heavy* as air, *if* we compare *equal volumes*, a cubic foot of water in sinking through one degree of temperature would raise 3,234 cubic feet of air one degree.

265. **Determination of the specific heats of solids and of liquids.**—Three methods have been employed for determining the specific heats of bodies: (i.) the method of melting ice, (ii.) the method of mixtures, and (iii.) that of cooling. In the latter, the specific heat of a body is determined by the time which it takes to cool through a certain temperature.

Method of the fusion of ice. This method of determining specific

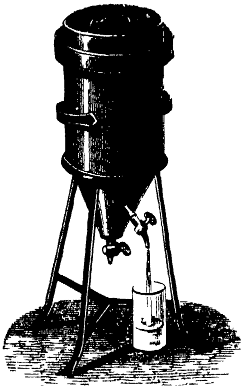


Fig. 237.

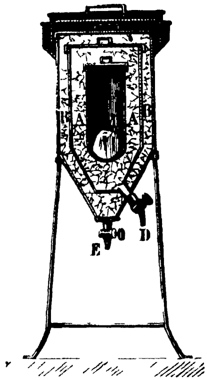


Fig. 238.

heats is based on the fact that to melt a pound of ice 80 thermal units are necessary, or more exactly 79·25. The substance to be determined is raised to a known temperature, 100° for instance, and is then rapidly placed in ice. In cooling from 100° to zero, the body melts a certain quantity of ice, which is collected in the form of water. From the weight of this water, from that of the body, and from the number of degrees through which it is cooled, the specific heat may be readily deduced by a simple calculation.

To facilitate the execution of this method, Lavoisier and Laplace devised an apparatus which is called the *ice calorimeter*. Fig. 237 gives a perspective view of it, and fig. 238 represents a section. It consists of three concentric tin vessels, M, A, B, each with covers

of the same material; in the central one is placed the body, M, whose specific heat is to be determined, while the two others, A and B, are filled with pounded ice. The ice in the compartment A is melted by the heated body, and the water resulting from the liquefaction runs off by the stopcock D, and is collected in a vessel; the ice in the compartment B cuts off the heating influence of the surrounding atmosphere. The stopcock E gives issue to the water which arises from the liquefaction of the ice in B.

Method of mixtures. This is a much more accurate and convenient method than that of the fusion of ice. In determining the specific heat of a solid body by this method, it is weighed and raised to a known temperature, by keeping it, for instance, for some time in a closed space heated by steam; it is then immersed in a mass of cold water, the weight and temperature of which are known. The water becomes heated by the heat given up by the body in cooling, and both come at last to the same temperature. From this common temperature, from the respective weights of the water and of the substance, and lastly from their temperatures at the time of mixture, the specific heat of the body is deduced by a simple calculation.

Substances	Specific heats	Substances	Specific heats
Water	1·0000	Zinc	0·0955
Turpentine	0·4259	Copper	0·0951
Wood charcoal	0·2411	Silver	0·0570
Sulphur	0·2025	Tin	0·0592
Graphite	0·2018	Antimony	0·0507
Thermometer glass	0·1976	Mercury	0·0333
Phosphorus	0·1895	Gold	0·0324
Diamond	0·1469	Platinum	0·0324
Iron	0·1138	Lead	0·0314
Nickel	0·1086	Bismuth	0·0308

It will be seen from the above table that water and oil of turpentine have a much greater specific heat than that of other substances, and more especially than the metals. It is from its great specific heat that water requires a long time in being heated or cooled; and that for the same weight and temperature, it absorbs or gives out far more heat than other substances. This double property is applied in heating by hot water, and it plays a most important part in the economy of nature.

Those bodies which have great specific heat, and therefore which require a great quantity of heat to raise them through a given temperature, also give out a great quantity in cooling through the same range. This difference between bodies as to the quantities of heat they contain may be illustrated by a simple experiment. A number of small bullets of various metals, iron, lead, bismuth, and copper, are heated to a temperature of about 200° C. by immersing them in hot oil; they are then placed on a cake of bees-wax, C D, about half an inch in thickness (fig. 239). It will then be found that the iron and copper melt themselves through, while the lead and bismuth make but little way, being unable to sink much more than half their way through the wax.

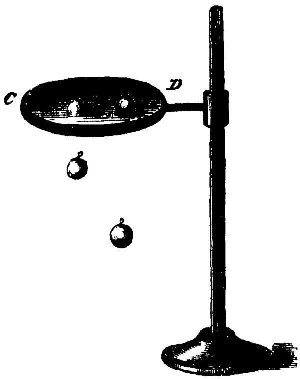


Fig. 239.

CHAPTER X.

STEAM ENGINES.

266. **Invention of the steam engine.**—*Steam engines* are undoubtedly the most important of the applications of the physical sciences to the arts. Based on the very great elastic force which aqueous vapour assumes at a high temperature (244) and on the condensation of this vapour by cooling (258), steam engines have created, in a small volume and at a small expense, very considerable motive power.

Their importance has caused much discussion and investigation as to their inventor, or rather inventors; for it is only by the successive efforts of several men of genius that these machines have attained their present simplicity and precision.

The history of the steam engine commences with Hero, the inventor of the fountain which bears his name, who invented, nearly two thousand years ago, a steam tourniquet, known as the *eolipyle*, analogous to the hydraulic tourniquet (fig. 65). The names of Salomon of Caux, and then of the Marquis of Worcester, are mentioned in the history of the steam engine.

Denis Papin, a French physicist, to whom is due the apparatus already described (252), was the first who caused a piston to ascend in a vertical cylinder, closed at the bottom and open at the top, by means of the elastic force of steam, and to descend by condensing this vapour by cooling; so that the piston which descended in virtue of atmospheric pressure had an up and down motion in the cylinder, which is still the principle of all steam engines. Papin, who was a Protestant, was obliged to fly from France, in consequence of the revocation of the Edict of Nantes, and the description and plan of his machine was published in Germany in 1690. He even made a model large enough to move a boat by means of paddle-wheels. In this model there was water underneath the piston at the bottom of the cylinder. When a furnace was placed under this, the water was converted into steam, and its elastic force raised the piston; when the piston was at the top of its course the

furnace was withdrawn; the cylinder cooling, the steam was condensed and the piston sank.

In 1705 Newcomen and Cawley constructed a steam engine, or 'fire-pump,' as it was then called, the object of which was to drain mines. In this engine (fig. 240) the steam was produced separately in a boiler *m*, below the cylinder *c*, containing the piston *p*. The condensation also was effected by cold water from a cistern, *n*, being injected into the cylinder through a cock, *b*. This was opened when the piston was to descend, and was closed after the descent; a second one, *a*, was opened through which steam entered, and so on. But the sides of the cylinder being cooled by this injection of cold water, the steam which filled it was partially condensed, until the sides were again heated; there was thus a considerable loss of steam, and therefore of fuel. The condensed water flowed out by a pipe, at the end of which was the valve *v*, which opened as the piston *p* descended. *w w* is the beam by which the motion is transmitted to the pump rod, *d*.

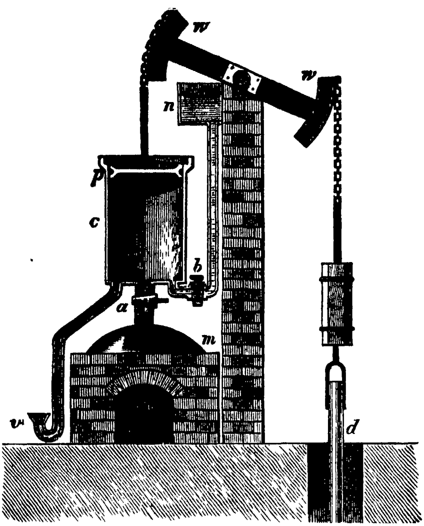


Fig. 240.

267. **Watt's improvements in the steam engine.**—James Watt, a mathematical instrument maker in Glasgow, had to repair the model of a Newcomen's engine belonging to the physical cabinet of the University. Struck by the enormous quantity of steam and of condensing water used by this engine, he entered upon a long series of researches and improvements, which he pursued with admirable perseverance for fifty years, without ever being content with the success he obtained. Thus it was that Newcomen's machine, successively changed and improved in all its parts, at last really became Watt's machine.

Condenser. Watt's first and principal invention was the *condenser.*

This name is given to a closed vessel quite distinct from the cylinder in which the piston moves, and only connected with it by a tube provided with a stopcock. In this vessel cold water is injected, and the vapour is condensed by opening the connecting stopcock. Thus, as the side of the cylinder is not cooled, all the steam which enters there is utilised. Thus there was effected so great an economy of steam, and therefore of fuel, that Watt, and Boulton his partner, having taken a patent, realised great profits by only requiring, for a certain number of years, a third of the saving in the consumption of coal, as compared with Newcomen's engine.

Single-acting engine. In Newcomen's engine, the cylinder of which was open at the top, the steam only lifted the piston ; and then, when the steam was condensed, the pressure of the atmosphere brought it down again ; whence the name *atmospheric engine*, by which it was designated. As the piston descended, air penetrated into the cylinder and cooled the sides, in consequence of which a portion of the vapour which penetrated into the cylinder was condensed until the sides were again heated. To remove this source of loss, Watt closed the cylinder altogether, and caused the vapour to act above the piston, so as to make it descend ; then by an arrangement of stopcocks, alternately opened and closed by the action of the engine itself, the steam passed simultaneously above and below the piston. This being pressed equally in opposite directions, remained in equilibrium ; so that a simple counterpoise acting by means of a lever at the end of a piston-rod raised the piston again, and so on. This machine, into which the air did not act, was called the *single-acting engine*, to express that the steam had a useful action on only one side of the piston.

The single-acting engine had the great disadvantage that it had no real force except when the piston was descending. It could transmit motion to pumps for emptying mines, because, for that, effort in only one direction was required ; but it would not furnish a sufficiently regular motion for many industries—for cotton manufactures, for instance. Hence Watt's task was not completed, but he was not long in finding another plan.

Double-acting engine. In this engine, one form of which we shall presently describe, and which is represented in fig. 241, the cylinder is closed both at the top and at the bottom, but the steam

acts alternately on the two faces of the piston ; that is to say, that by a system of stopcocks, opened and closed by the engine itself, when the lower part of the cylinder communicates with the condenser, the upper part, on the contrary, is connected with the boiler, and the steam, acting in all its force on the piston, causes it to descend. Then when this is at the bottom of its stroke the parts change ; the top of the cylinder is in connection with the condenser, and the bottom with the boiler ; the piston rises again, and so forth, whence results an alternating rectilinear motion which is changed into a continuous circular motion, as will be presently described (268).

Air-pump. Watt completed his engine by the addition of three pumps, which are worked by the engine, and play an important part. For the cold water of the condenser becomes rapidly heated by the heat which the steam gives up to it (258), and this water, soon reaching 100 degrees, would no longer condense the steam. Moreover, the air, which is always dissolved in cold water, is liberated in the boiler, owing to the increase in temperature. Now this air, passing both above and below the piston, would soon stop its motion. To prevent these two injurious effects, Watt applied to the engine a suction-pump, which continually withdrew from the condenser the air and water which tended to accumulate there.

Feed-pump and cold-water-pump. The two other pumps which Watt added are the feed-pump and the cold-water-pump. The first is a force-pump which sends into the boiler the hot water withdrawn from the condenser by the air-pump, thus producing a considerable saving in fuel. The other is a suction-pump, which raises, either from a well or a river, or some other source, the cold water intended to replace that heated in the condenser and withdrawn by the air-pump.

Besides the important parts which have thus been described, we owe to Watt the arrangement for distributing the steam alternately above and below the piston : the *regulator*, whose function, when the machine works too slowly, is to admit more steam into the cylinder, and, on the other hand, to diminish the quantity when the velocity is too great. Lastly, the *parallelogram*, devised by Watt, which imparts to the piston rod a rectilinear motion. It may be added that Watt, who had begun life as a philosophical instrument maker, carried into the execution of these great pieces of machinery the same perfection as is required for the best scientific instruments.

268. **Description of the double-acting engine.**—We have already seen that the double-acting engine is that in which the

steam acts alternately above and below the piston (267). Fig. 241 represents an engine of this kind, and fig. 245 gives a section of the

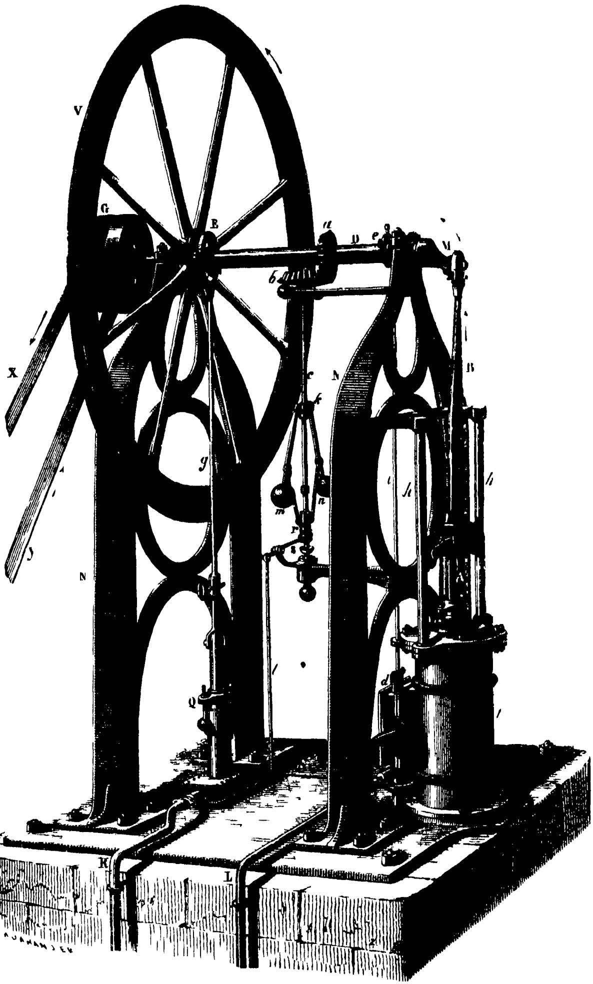


Fig 241

cylinder, of the piston, and of the distribution of steam. The entire engine is of iron. To the piston T is fixed a rod A, which slides with gentle friction in a tubulure U placed at the centre of the plate which closes the cylinder (fig. 241). As it is very important that no steam shall escape between the piston rod and this tubulure, the latter is formed of two pieces, one attached to the plate, while the other, which fits in the first, can be pressed as tightly as is desired, so as to compress the material soaked with fat which is between the two tubulures. This arrangement is called a *stuffing-box*; it prevents the escape of steam without interfering with the motion of the piston.

On the two sides of the cylinder are two columns *hh*, which guide the piston rod in its upward and downward motion. The end of the piston rod is connected with a long piece B, called the *connecting rod*, which in turn is jointed with a shorter piece M, called the *crank*, the length of which is just half that of the stroke of the piston. This is rigidly fixed to a *horizontal shaft*, D, so that it cannot move without transmitting its motion.

By means of this connecting rod and crank, the alternating rectilinear motion of the piston and of the rod is changed into a continuous circular motion. For the rod, during the ascent of the piston, acts upwards upon the crank, making it turn in the direction of the arrow. When the piston is at the top of its stroke, the motion rod and the crank are one in front of the other. As the piston descends, the motion rod again acts, so as always to turn it in the same direction; and when the piston is at the bottom of the stroke, they are again vertical, but one is in the prolongation of the other. Hence it follows that the axle, which has made half a turn during the ascent, makes a second one during the descent, and thus performs a complete revolution during each double oscillation of the piston.

To transmit the motion to machinery, on the axle D is fixed a sheave, on which works an *endless band* XY of leather, which works on another sheave fixed to the machinery to be turned. Moved by the first sheave, this band communicates its motion to the second; in this manner the motion is transmitted to all the workshops of a large factory. On the right of the fixed sheave, G, there is a second, which is not fixed to the horizontal shaft: this is the movable sheave. Its object is to suspend all the motion in the machine without stopping the steam engine. By means of an iron fork not seen in the figure, which encloses the band, the latter may be slid from the fixed to the movable sheave.

As this latter is not connected with the horizontal shaft, it does not unite with it, and does not transmit its motion to the band.

On the horizontal shaft is a very large iron wheel, V, called the *fly-wheel*, which is necessary for keeping up the motion. For each time that the piston is at the top or bottom of its stroke, there is a momentary arrest, during which the motion of the whole machine tends to stop. These are called the *dead points*. It is then that the fly-wheel, in virtue of its inertia and of its acquired velocity, moves the horizontal shaft, and thus keeps up a regular motion.

269. **Excentric. Valve-chest.**—The excentric is an arrangement by which a continuous circular motion is changed into an

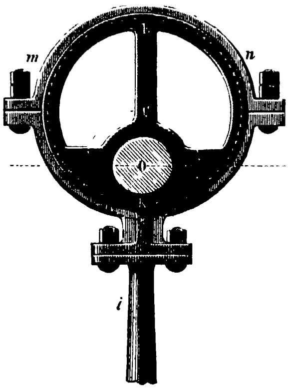


Fig. 242.

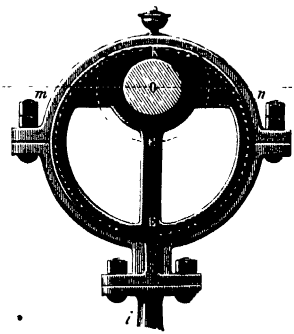


Fig. 243.

alternating rectilinear motion. It is very frequently used in machinery.

One of these is fitted to the horizontal shaft at E, and the other at *e*. The former works the *feed-pump*, and the latter the *valve-chest*. The action of each is the same. Figures 242 and 243 represent it on a larger scale, in two exactly opposite positions. It consists of a circular piece KE, fixed to the horizontal shaft, but in such a manner that the centre of rotation does not coincide with the centre of the piece; the latter being at C, the former at O. It follows from this construction that the point C constantly describes a circumference about O, which is represented in the drawing by a

dotted line. Hence in each half-turn it passes from the position represented in fig. 242 to that represented in fig. 243, and *vice versâ*. So that the point C, in turning about the point O, does really perform an up and down motion.

To use this motion, the excentric is surrounded by a *collar*, *mn*, in which it can turn freely like an axle in its box; hence, during the rotation of the horizontal shaft, the collar shares the ascending and descending motion of the point C, but not its rotatory motion. The excentric alone turns, the collar only rises and sinks. By thus transmitting its motion to a rod *i*, it works the valve-chest.

Valve-chest. We have still to describe the valve-chest, the arrangement by which steam passes alternately above and below the piston. Fig. 244 presents a vertical section of this valve-chest and of the cylinder. The steam enters the valve-chest from the boiler by the brass tube *x*. From the valve-chest two conduits, *a* and *b*, are connected with the cylinder, one above and the other below. If they were both open at once, the steam acting equally on the two faces of the piston would keep it at rest. But one of these is always closed by a *slide valve*, *y*, fixed to a rod, *i*. This moves alternately, up and down, by means of an excentric, *e*, placed on the horizontal shaft. In fig. 245 the slide-valve closes the conduit *a*, and allowing the steam to enter at *b*, below the piston, the latter rises. But when it reaches the top of the stroke the excentric has passed from the position represented in fig. 245 to that in fig. 244: hence the rod, *i*, sinks, and with it the slide-valve, which then closes the conduit *b*, and allows the steam to enter at *a* (fig. 244). The piston then sinks, and so forth at each displacement of the slide valve.

In completing this account of the manner in which steam is distributed, it remains to explain what happens when the steam presses below the piston (fig. 245). It must not remain above, otherwise the piston could not move. But while the steam enters below by the conduit *b*, the top of the cylinder, by means of the conduit *a*, is connected with a cavity O, from which passes a tube L. Through this tube the steam which has already acted upon the piston passes into the atmosphere, or else is condensed in a vessel filled with cold water, which has been already mentioned, *the condenser* (267). If, on the other hand, the piston sinks, the slide-valve being in the position of fig. 244, the vapour below the piston passes by the conduit *b*, to the cavity O, and to the tube L.

270. **Regulator.**—The object of this arrangement is to regulate the quantity of steam which reaches the valve-chest, increasing it when the machine works too slowly and diminishing it when it works too rapidly. It consists of a parallelogram *kr* (fig. 241), each apex of which is jointed. A toothed wheel, *a*, connected with the horizontal shaft, transmits its motion to a similar wheel, *b*, fixed to the rod *c*, which supports the parallelogram. This turns then with the rod the more rapidly the greater the velocity of the machine. But the two upper arms are provided with two solid balls, *m* and *n*; moreover, a socket *r*, to which are attached the two lower arms, is not fixed to the rod *c*, but can glide along it. Hence the centrifugal force (29) acting on the balls *m* and *n* makes them diverge, the parallelogram opens, and the socket rises. It transmits its motion to a lever, *s*, the short arm of which, being lowered, presses upon a long rod, *t*. This, inclining the lever O, effects a small rotation in a valve, *b*, placed in the tube *x*, by which steam comes (fig. 245). This valve, either by stopping the tube *x*, or by leaving it open, admits more or less steam.

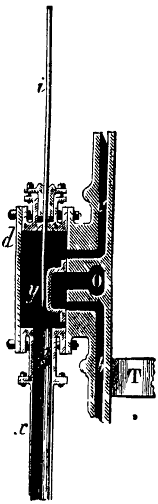


Fig. 244.

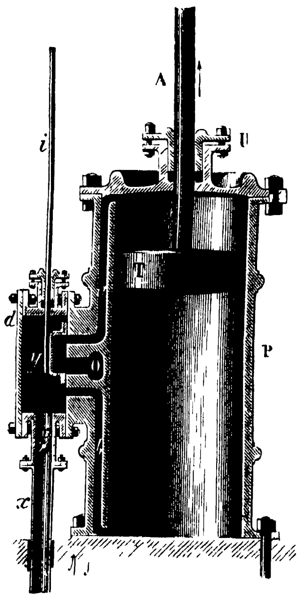


Fig. 245.

271. **Feed-pump.**—The object of this, as its name implies, is to renew the water in the boiler as fast as it evaporates. In fig. 241 this pump, placed at Q, on the left of the drawing, receives its motion from an excentric by means of a long rod, and it works both as *cold-water-pump* and as *feed-pump*; as cold-water-pump, in-

asmuch as it withdraws water from a well by a suction-pipe placed below the engine; and as feed-pump by its then forcing water into the boiler by the pipe R.

272. **Various kinds of steam engines.**—A *low pressure engine* is one in which the pressure of the vapour is not much more than that of an atmosphere; and a *high pressure engine* is one in which the pressure of the steam usually exceeds this amount considerably. Low pressure engines are mostly *condensing engines*; in other words, they generally have a condenser where the steam becomes condensed after having acted on the piston; on the other hand, *high pressure engines* are frequently without a condenser; the locomotive is an example.

If the communication between the cylinder and the boiler remains open during the whole motion of the piston, the steam retains practically the same elastic force, and is said to act *without expansion*; but if, by a suitable arrangement of the slide-valve, the steam ceases to pass into the cylinder when the piston is at $\frac{2}{3}$ or $\frac{3}{4}$ of its course, then the vapour *expands*; that is to say, in virtue of its elastic force, which is due to the high temperature, it still acts on the piston and causes it to finish its course. Hence a distinction is made between *expanding* and *non-expanding* engines.

The principle of expansion is not applicable to low pressure engines, for the elastic force of the steam is not great. But for high or mean pressure engines it not only effects a great saving in steam, and therefore in fuel, but it regulates the motion, by diminishing the pressure the moment the acquired velocity of the piston tends to increase.

273. **Work of an engine. Horse-power.**—The work of an engine is measured by the mean pressure on the piston, multiplied by the area of the piston, multiplied by the length of the stroke. In England the unit of work is the *foot-pound*: that is, the work performed in raising a weight of one pound through a height of a foot. Thus, to raise a weight of 14 pounds through a height of 20 feet would require 280 foot-pounds. In France the *kilogrammetre* is used; that is, the work performed in raising a kilogramme through a metre. This unit corresponds to 7·233 foot-pounds.

The *rate of work* in machines is the amount of work performed in a given time; a second or an hour, for example. In England the rates of work are compared by means of *horse-power*, which is a conventional unit, and represents 550 foot-pounds in a second. In France a similar unit is used, called the *cheval-vapeur*, which

represents the work performed in raising 75 kilogrammes through one metre in a second. It is equal to about 542 foot-pounds per second.

Thus, suppose a steam engine with a piston, the area of which is 30 square inches, and its length of stroke 18 inches, and that it makes 84 up and down strokes in a minute. Suppose further that the mean pressure on the piston is equal to 14 pounds on a square inch. The work that the steam engine performs is

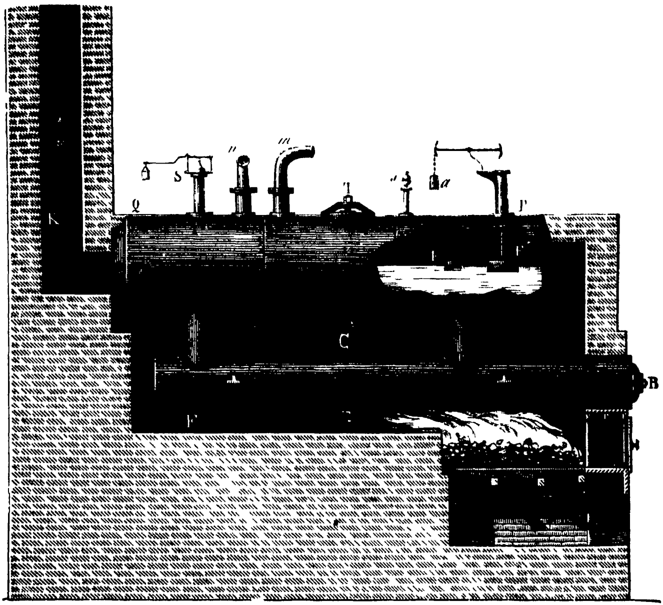


Fig. 246.

equal to $30 \times 14 \times 84 \times 2 \times 1\frac{1}{2} = 105{,}840$ foot-pounds per minute. From this must be deducted the work expended in overcoming the friction of the machine, working the pumps, etc. Taking these at 35 per cent., there remains a useful effect of 11,466 foot-pounds per minute, which, from what has been said above, represents $2\frac{1}{4}$ horse-power.

274. **Steam-boiler.**—We have still to describe the steam-boiler, or the arrangement by which the steam is generated, and its various

accessories. *Fig.* 246 gives a longitudinal and fig. 247 a transverse section of a steam boiler and its furnace. The steam boiler consists of a long wrought-iron cylinder, P Q, with hemispherical ends. Below are two cylinders, B B, of smaller diameter, which are called *heaters*, and which are connected with the boiler by two strong tubes. The object of these heaters is to expose a greater surface to be heated. They are full of water, as also are the tubes which connect them with the boiler, which is only half full.

The feed-water sent by the pump, Q, fig. 241, reaches the boiler by a tubulure, *n*, which is immersed to the bottom to prevent cold water from condensing steam; a second tubulure, *m*, leads the vapour to the valve-chest. In the middle of the boiler is an oval hole, called a *manhole*, the object of which is to allow workmen to enter the boiler when it needs repairs. This hole, as well as two front ones, B B, of the heaters, are closed by what are called *autoclaves*. Here the cover instead of being on the outside is on the inside. A screw T fixed to this cover makes it press against the sides; and as the pressure of the steam acts in the same direction, the greater the pressure the more tightly is the vessel closed.

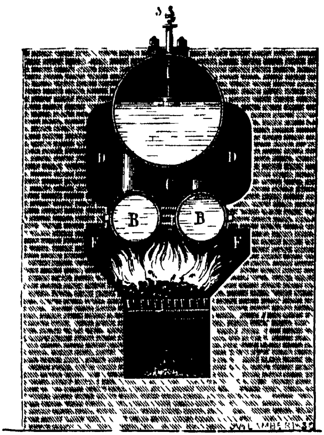


Fig 247

The furnace in which the boiler is placed is so constructed as to multiply the surface heated, and to render the combustion as complete as possible. The products of combustion pass into tall chimneys, which from their great height increase the draught and thereby promote combustion.

275. **Float.**—This is a small apparatus, the object of which is to show the level of water in the boiler. It consists of a lever, at one end of which is a piece of stone, F, and at the other a counterpoise, *p*, fig. 249. The mass F weighs more than the counterpoise *p*; but as it is immersed in water, and thus loses part of its weight (97), it is in equilibrium, and the lever is horizontal so long as the level of water is at the desired height. But it sinks when there

is too little water, and rises in the contrary direction when there is too much. Guided by these indications, the stoker can regulate the supply of water.

276. **Safety-valve.**—The pressure of steam in the boiler is measured by means of the manometer (137). But this instrument would not prevent explosions if its indications were neglected. Hence safety-valves are placed on boilers similar to that which Papin adopted in his digester (252). Fig. 248 represents on a larger scale one of these valves. It consists of a metal stopper, *c*, closing a tubulure, A, fixed on the boiler. To prevent this from sticking to the sides, the metal stopper is hollowed on three sides as seen at *s*. It thus more resembles a clack-valve than an ordinary stopper. On the piece rests a movable lever, *ab*, loaded with a weight *p*. By moving this along the lever the load on the valve can be modified at will. For this purpose marks are placed which indicate the position of the load corresponding to a given pressure. Thus, suppose it is desired that the pressure shall not exceed 5 atmospheres, the weight is placed at the division 5 on the lever. Then, as long as the pressure is less than 5, the safety-valve remains closed; but if the pressure exceeds this amount, the valve opens and gives exit to the steam, thus preventing an explosion.

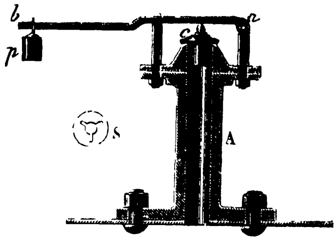


Fig. 248.

277. **Safety-whistle.**—This is another safety apparatus, which indicates at a distance when the level of water in the boiler is too low. It consists of a float, F (fig. 249), supported by a lever *ih*, which moves about the joint *c*; a counterpoise, *p*, balances the float, and a small conical stopper, *a*, fixed to the lever, closes a tubulure on the boiler. This tubulure is closed at the top by two hollow hemispheres. In the centre of the lower one is a disc, which does not quite reach the edges. Between the two hemispheres is a circular interval through which vapour escapes when the cone *a* does not close the tubulure.

As long as the water is at the right height the float F is raised, and presses the cone against the tubulure; but if the level sinks, the float sinks, and with it the cone. The steam escapes round the disc *e*, and gives a very acute sound in striking against the edges

of the upper hemisphere, which are bevelled. The system constitutes, in fact, a short stopped organ pipe, and yielding therefore a very acute sound (195).

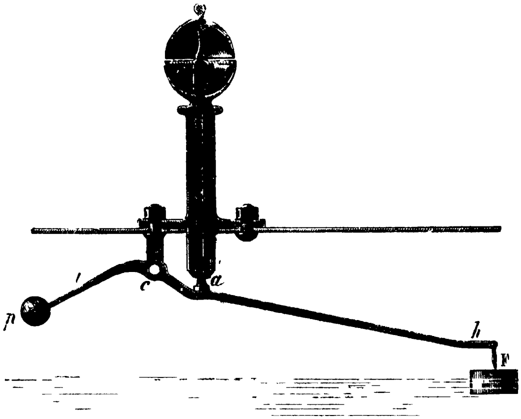


Fig. 249.

On locomotives a similar whistle enables the driver to signal at a great distance by opening a stopcock, which allows the steam to escape.

CHAPTER XI.

HYGROMETRY.

278. **Hygrometry.**—The province of *hygrometry* is to determine the quantity of aqueous vapour contained in a given volume of air. The quantity is very variable; the atmosphere can scarcely be said to be ever completely saturated with vapour, even in our climate. Nor is it ever completely dry; for if *hygroscopic substances*—that is to say, substances with a great affinity for water, such as chloride of calcium, sulphuric acid, burnt lime, etc.—be at any time exposed to the air, they absorb more or less aqueous vapour.

The degree of moisture does not depend on the absolute quantity of aqueous vapour present in the air, but on the greater or less distance of the air from its point of saturation. When the air is cold, it may be moist with very little vapour, and, on the contrary, when it is warm, it may be very dry, even with a large quantity of vapour. In summer the air usually contains more aqueous vapour than in winter, notwithstanding which it is less moist, because as the temperature is higher the vapour is farther from its point of saturation. When a room is warmed, the quantity of moisture is not diminished, but the moisture of the air is lessened, because its point of saturation is raised. The air may thus become so dry as to be injurious to health, and accordingly it is usual to place vessels of water on the stoves used for heating.

The quantity of vapour contained in the air varies greatly with the seasons, the climates, the temperature, and various local causes. A mean degree of moisture is best suited to the animal economy. In a state of great dryness, as is the case, for instance, during the prevalence of north-east winds, the cutaneous transpiration is too abundant, the skin dries up and chaps, and general discomfort ensues. In an atmosphere which is too moist, transpiration is slower, and a feeling of depression and heaviness is felt. Hence it is necessary to regulate in a suitable manner the moisture of dwelling rooms, so as to avoid these two extremes.

279. **Hygroscopes.**—There are two classes of instruments by which the hygrometric state of the air may be ascertained. One class, called *hygroscopes*, simply tell whether the air is more or less moist, but give no indications as to the quantity of moisture it contains ; others, called ***hygrometers***, enable us to measure it with some accuracy.

All substances which absorb aqueous vapour, like common salt and many others known as *deliquescent salts*, may serve as hygroscopes. This is also the case with a great number of animal and vegetable substances, such as paper, parchment, hair, catgut, etc., which lengthen as the air becomes moist, but contract as it becomes dry, and thus give an indication of the greater or less quantity of vapour in the air.

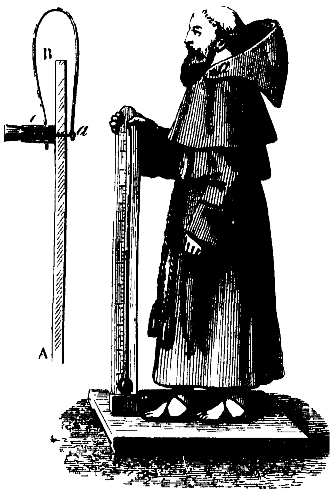


Fig. 250.

A great number of instruments have been constructed which serve as *hygroscopes*. One of the commonest is that represented in fig. 250. It consists of a small figure representing a monk fixed on a support ; the head is provided with a cowl of thin cardboard, movable about the point *a*, where it is attached to the end of a small piece of twisted catgut. The other end of this is fixed in a tubulure, *o*, as seen in the section. The catgut twisting as it becomes dry, and untwisting as it is moist, moves the cowl, which is carefully arranged so that the head is covered when the atmosphere is moist, and uncovered when it is dry.

This instrument, and all others of the same class, only change slowly, and their indications are always behindhand with the state of the weather ; nor are they, moreover, very exact.

280. **Hygrometric state of the air.**—By this term we do not understand the actual quantity of vapour present, but the ratio of the weight of vapour which the air actually contains, to that which it would contain if it were completely saturated. Thus, if we say

that the air is *three fifths* saturated, we mean that it contains three fifths of the vapour which it would contain in a state of saturation.

281. **Hygrometers.**—The most exact of all hygrometers is the *chemical hygrometer*. This consists essentially of an arrangement by which a given measured volume of air is passed through a series of drying tubes—that is, tubes containing some hygroscopic substance, such as chloride of calcium, or pumice saturated with sulphuric acid. These tubes, having been previously weighed, are weighed again after the operation; an increase of weight is observed, which is due to the moisture absorbed by the hygroscopic substance, and this increase represents the weight of the moisture in the volume of air taken.

This method is very exact, but it is both difficult and tedious of execution.

More convenient than the above are what are called *condensation hygrometers*, in which the vapour of the atmosphere is made to condense on a body artificially cooled. This may be illustrated by having a small cup of polished metal in which is placed a lump of ice and a delicate thermometer. When the vessel gradually cools in a moist atmosphere, the layer of air in immediate contact with it cools also, and a point is ultimately reached at which the vapour present is just sufficient to saturate the air: the least diminution of temperature then causes a precipitation of moisture on the cup in the form of dew. When the temperature rises again, the dew disappears, and the mean of these two temperatures is taken as the *dew point*.

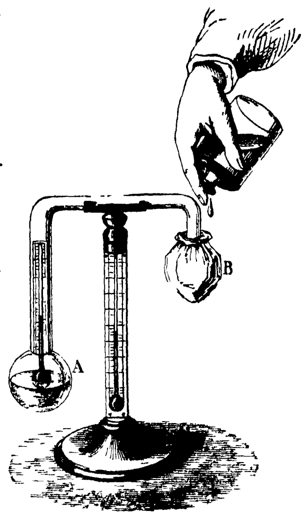


Fig. 251.

A good example of an instrument of this class is met with in *Daniell's hygrometer*. This consists of two glass bulbs at the extremities of a glass tube bent twice (fig. 251). Tho bulb A is two thirds full of ether, and a very delicate thermometer dips in it; the rest of the space contains nothing but the vapour of ether, the ether having been boiled before the bulb B was sealed. The bulb B

is covered with muslin, and ether is dropped upon it. The ether in evaporating cools the bulb, and the vapour contained in it is condensed. The internal tension being thus diminished, the ether in A forms vapours which condense in the other bulb, B. In proportion as ether distils from the lower to the upper bulb, the ether in A becomes colder, and ultimately the temperature of the air in immediate contact with A sinks to that point at which its vapour is just more than sufficient to saturate it, and the excess is accordingly deposited on the outside as a ring of dew corresponding to the surface of the ether. The temperature of this point is noted by means of the thermometer in the inside. The addition of ether to the bulb B is then discontinued, the temperature of A rises, and the temperature at which the dew disappears is noted. In order to render the deposition of dew more perceptible, the bulb A is made of black glass.

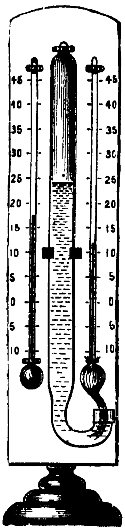


Fig. 252.

These two points having been determined, their mean is taken as that of the dew point. The temperature of air at the time of the experiment is indicated by the thermometer on the stem. The tension f, corresponding to the temperature of the dew point, is then found in the table of tensions (253). This tension is exactly that of the vapour present in the air at the time of the experiment. The tension, F, of vapour saturated at the temperature of the atmosphere is found by means of the same table; the quotient, obtained by dividing f by F, represents the hygrometric state of the air. For instance, the temperature of the air being $15°$, suppose the dew point is $5°$. From this table the corresponding tensions are $f = 6{\cdot}53$ millimetres, and $F = 12{\cdot}70$ millimetres, which gives $0{\cdot}514$ for the ratio of f to F, or the hygrometric state.

A very convenient form of hygrometer, and one whose use is rapidly extending, is that known as the *psychrometer* or *wet bulb hygrometer*, which is based on the principle that a moistened body evaporates in the air more rapidly in proportion as the air is drier (248); and, in consequence of this evaporation, the temperature of the body sinks. The application of the principle to this purpose was first suggested by Leslie. The form of the apparatus usually adopted in this country is due to Mason. It consists of two delicate

thermometers placed on a wooden stand (fig. 252). One of the bulbs is covered with muslin, and is kept continually moist by being connected with a reservoir of water by means of a string. Unless the air is saturated with moisture, the wet bulb thermometer always indicates a lower temperature than the other, and the difference between the indications of the two thermometers is greater in proportion as the air can take up more moisture.

According to Glaisher, the temperature of the dew point may be obtained by multiplying the *difference* between the temperatures of the wet and dry bulb by a factor which depends on the temperature of the air at the time of observation, and subtracting the product thus obtained from this last-named temperature. The following are the numbers :—

Dry bulb temperature F.°	Factor	Dry bulb temperature F.°	Factor
Below 24°	8·5	34 to 35°	2·6
24 to 25	7·3	35—40	2·5
25—26	6·4	40—45	2·3
26—27	6·1	45—50	2·1
27—28	5·9	50—55	2·0
28—29	5·7	55—60	1·8
29—30	5·0	60—65	1·8
30—31	4·6	65—70	1·7
31—32	3·6	70—75	1·5
32—33	3·1	75—80	1·3
33—34	2·8	80—85	1·0

These are often known as *Glaisher's factors.* The temperatures are expressed on the Fahrenheit scale. As an example : if the temperature of the wet bulb is 49° and that of the dry bulb 54°, then the dew point is 44°—that is, at this temperature the moisture present in the atmosphere is just sufficient to saturate it.

CHAPTER XII.

METEOROLOGICAL PHENOMENA WHICH DEPEND UPON HEAT.

282. **Meteorology.**—Meteorology is that branch of physics which is concerned with the phenomena which occur in the atmosphere; such, for instance, as variations in the temperature of the air, wind, rains, storms, electrical phenomena, etc. Though of recent origin, this science is a most important application of the physical sciences, and furnishes useful information to navigation, to agriculture, and to hygiene.

283. **Mean temperature.**—The *mean daily temperature*, or simply *temperature*, is that obtained by adding together 24 hourly observations, and dividing by 24. A very close approximation to the mean temperature is obtained by taking the mean of the highest and lowest temperatures of the day and of the night, which are determined by means of maximum and minimum thermometers (209). These ought to be protected from the sun's rays, raised above the ground, and be far from all objects which might influence them by their radiation. The lowest mean daily temperature is at 4 A.M., and the highest at 2 P.M.

The *temperature of a month* is the mean of those of 30 days, and the *temperature of the year* is the mean of those of 12 months. The highest mean monthly temperature is in July, and the lowest in January. The temperature of a place is the mean of its annual temperature for a great series of years. The mean temperature of London is 10°·35 C., or 50°·63 F. The temperatures in all cases are those of the air and not those of the ground.

284. **Causes which modify the temperature of the air.**—The principal causes which modify the temperature of the air are the latitude of a place, its height—that is, its distance above the sea—the direction of the winds, and the proximity of seas.

Influence of the latitude. The temperature of the air and of the ground diminishes from the equator towards the poles. This is due to the fact that the sun's rays, which are perpendicular at the equator, are more and more inclined as we come nearer the poles.

Now, the more acute is the angle under which the rays of heat fall upon a body, the less is the body heated ; hence the heat absorbed decreases from the equator to the poles, for the rays are then more and more oblique. Yet, as in summer the days are longer as we get nearer the north, the loss due to the increasing obliquity of the sun is partially compensated by the sun remaining longer above the horizon. Under the equator, where the length of the days is constant, the temperature is almost invariable; in the latitude of London, and the more northerly countries, where the days are very unequal, the temperature varies greatly ; but in summer it sometimes rises almost as high as under the equator. The lowering of the temperature produced by the change in latitude alone is small ; thus in a latitude of 115 miles north of ours, the temperature is only 1° C. lower.

Influence of height. The height of a place has a much more considerable influence on the temperature than its latitude. In the temperate zone an ascent of 540 feet corresponds in the mean to a diminution of 1° C.

The cooling as we ascend in the atmosphere has been observed in balloon ascents, and a proof of it is seen in the perpetual snows which cover the highest mountains, even under the torrid zones. The height at which snow remains unmelted through the year, or the *line of perpetual snow* met with, differs in different places. On the Andes it commences at a height of 14,760 feet, and on the Alps at 8,880 feet.

Direction of winds. As winds share the temperature of the countries which they have traversed, their direction exercises great influence on the air in any place. In our climate the hottest winds are the south, then come the south-east, the south-west, the west, the east, the north-west, north, and, lastly, the north-east, which is the coldest. The character of the wind changes with the seasons ; the east wind, which is cold in winter, is hot in summer.

Proximity of the seas. The neighbourhood of the sea tends to render the temperature of the air uniform, by heating it in winter, and cooling it in summer. The average temperature of the sea in equatorial and polar countries is always different from that of the atmosphere. With reference to the uniformity of the temperature, it has been found that in temperate regions—that is, from 25 to 50 degrees of latitude—the difference between the maximum and minimum temperature of a day does not exceed, on the sea 2° to 3° C.: while upon land it amounts to 12° to 15°. In islands the uniformity of

temperature is very perceptible, even during the greatest heats. In continents, on the contrary, the winters for the same latitudes become colder, and the difference between the temperature of summer and winter becomes greater.

285. **Gulf Stream.**—A similar influence to that of the winds is exerted by currents of warm water. The mildness of the climate in the north-west of Europe is usually assigned to one of these, the Gulf Stream. This great body of water, taking its origin in equatorial regions, flows through the Gulf of Mexico, whence it derives its name; passing by the southern shores of North America, it makes its way in a north-westerly direction across the Atlantic, and finally washes the coast of Ireland and the north-west of Europe generally. It traverses 3,000 miles in about seventy-eight days. Its temperature in the Gulf is about 28° C., and is generally a little more than 5° C. higher than the rest of the ocean, on which it floats owing to its lower specific gravity. To its influence is due the milder climate of western Europe as compared with that of the opposite coast of America; thus the river Hudson, which is in the same latitude as Rome, is frozen over three months in the year. It also causes the polar regions to be separated from the coast of Europe by a girdle of open sea; and hence the harbour of Hammerfest is open the year round. Besides its influence in thus moderating climate, the Gulf Stream is an important help to navigators.

286. **Isothermal lines.**—When all the points on a map whose temperature is known to be the same are joined, curves are obtained, which Humboldt first described, and which he called *isothermal lines*. If the temperature of a place only varied with the obliquity of the sun's rays—that is, with the latitude—isothermal lines would all be parallel to the equator; but as the temperature is influenced by many local causes, especially by the height above the sea level, the isothermal lines are always more or less curved. On the sea, however, they are almost parallel. A distinction is made between *isothermal lines*, *isotheral lines*, and *isochimenal lines*, where the *mean general*, the *mean summer*, and the *mean winter* temperatures are respectively constant. An *isothermal zone* is the space comprised between two isothermal lines. Kupfer also distinguishes *isogeothermal lines*, where the mean temperature of the soil is constant.

287. **Climate.**—By the *climate* of a place is understood the whole of the meteorological conditions to which a place is subjected, its mean annual temperature, summer and winter tempera-

tures, and the extremes within which these are comprised. Some writers distinguish seven classes of climates according to their mean annual temperature—a *hot climate* from 30° to 25° C.; a *warm climate*, from 25° to 20° C.; a *mild climate*, from 20° to 15° C.; a *temperate climate*, from 15° to 10° C.; a *cold climate*, from 10° to 5° C.; a *very cold climate*, from 5° to zero; and an *arctic climate*, where the temperature is below zero.

Those climates, again, are classed as *constant climates*, such as the Havannah and Quito, where the difference between the mean summer and winter temperature does not exceed 6° to 8°; *variable climates*, such as Paris and London, where the difference amounts to from 16° to 20°; and *extreme climates*, such as those of Pekin and New York, where the difference is greater than 30°. Island climates are generally but little variable, as the temperature of the sea is constant; and hence the distinction between land and sea climates.

There is a great difference between a *land* and a *sea* climate (284). The former is characterised by a greater range of temperature than the latter. Thus in the north-east of Ireland ice scarcely forms in winter, and the myrtle flourishes as in Portugal; yet this is in the same latitude as Königsberg in Prussia, where the mean annual temperature is 5° C., the range being from $-3°\cdot5$, the mean monthly temperature in January, to $13°\cdot6$, that of July. Winter in Plymouth is not colder than in Florence or Montpellier, yet grapes do not flourish there in the open air; for while they can stand a somewhat severe cold in winter, they require a hot summer to become ripe. In Irkutsk in Siberia, where the ground is constantly frozen at a depth of three feet, oats and rye can be grown, for the short but hot summer is sufficient to ripen them; while in Iceland, where the mean annual temperature is much higher, and the cold in winter is inconsiderable, no cereals can be grown, for the low summer temperature is insufficient to bring them to maturity.

The reason of this is that the land absorbs and radiates heat easily; it thus becomes more easily heated and more rapidly cooled than the sea, which mainly from its great specific heat (264) is not so rapidly heated, but on the other hand does not so soon again part with the heat it has acquired.

But the temperature is by no means the only characteristic which influences the climate of a place; there are, in addition, the moisture of the air, the quantity and frequency of the rains, the number of storms, the direction and intensity of the winds, and the nature of the soil.

FOG. RAIN. DEW.

288. **Fogs and mists.**—When aqueous vapour, rising from a vessel of boiling water, diffuses in the colder air, it is condensed; a sort of cloud is formed which consists of a number of small hollow vesicles of water, which remain suspended in the air. These are usually spoken of as vapour, yet they are not so, at any rate not in the physical sense of the word; they are, in reality, partially condensed vapour.

When this condensation of aqueous vapour is not produced by contact with cold solid bodies, but takes place throughout large spaces of the atmosphere, the effect is to form *fogs* or *mists*, which in fact are nothing more than the appearance seen over a vessel of hot water.

A chief cause of fog consists in the moist soil being at a higher temperature than the air. Such fogs are of frequent occurrence in autumn. The vapours which then rise condense and become visible. In all cases, however, the air must have reached its point of saturation before condensation takes place. Fogs are also produced when a current of hot and moist air passes over land or water at a lower temperature than its own, for then, the air being cooled, as soon as it is saturated, the excess of vapour present is condensed. In this way are formed the winter fogs.

The distinction between mists and fogs is one of degree rather than of kind. A fog is a very thick mist.

289. **Clouds.**—*Clouds* are masses of vapour condensed into little drops or vesicles of extreme minuteness, like fogs and mists, from which they only differ in occupying the higher regions of the atmosphere; they always result from the condensation of vapour which rises from the earth or the sea. There is no essential difference between a fog and a cloud; a cloud is a fog at a great height; a fog is a cloud low down. According to their appearance, they have been divided by Howard into four principal kinds: the *nimbus*, the *stratus*, the *cumulus*, and the *cirrus*. These four kinds are represented in fig. 253, and are designated respectively by one, two, three, or four birds on the wing.

The *cirrus* consists of small whitish clouds, which have a fibrous or wispy appearance. The name of *mares-tails*, by which they are generally known, well describes their appearance. Of all clouds these are the highest, for they present the same appearance on the tops of high mountains as they do in valleys. Their height has been determined at about 7,500 yards. From the low temperature of

the spaces which they occupy, it is more than probable that cirrus clouds consist of frozen particles ; and hence it is that haloes, coronæ, and other optical appearances, produced by refraction and reflection from ice crystals, appear almost always in these clouds and their derivatives, more particularly cirro-stratus. Their appearance often precedes a change of weather.

The *cumulus* are rounded spherical forms which look like mountains, piled one on the other, and are also known as *woolpack cloud*. They are more frequent in summer than in winter, and, after being

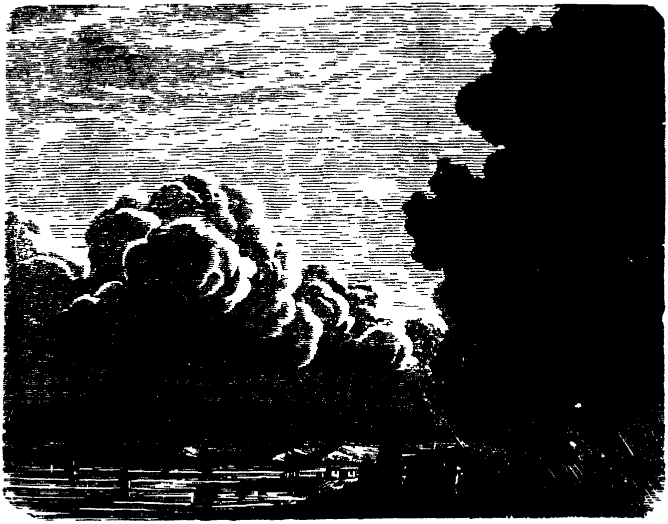


Fig. 253

formed in the morning, they generally disappear towards evening. If, on the contrary, they become more numerous, and especially if surmounted by cirrus clouds, rain or storms may be expected. Their height varies from 1,516 to 1,730 yards.

Stratus clouds consist of very large and continuous horizontal sheets, which chiefly form at sunset, and disappear at sunrise. They are frequent in autumn and unusual in springtime, and are lower than the preceding. The height is about 680 yards. The stratus is generally a fine weather cloud.

The *nimbus* or rain clouds, which are sometimes classed as one

of the fundamental varieties, are properly a combination of the three preceding kinds. They affect no particular form, and are solely distinguished by a uniform grey tint, and by fringed edges. They are indicated on the right of the figure by the presence of one bird. Their height varies from about 1,200 to 2,400 yards.

The fundamental forms pass into one another in the most varied manner; Howard has classed these transitional forms as *cirro-cumulus*, *cirro-stratus*, and *cumulo-stratus*, and it is often very difficult to tell, from the appearance of a cloud, which type it most resembles. The cirro-cumulus is most characteristically known as a 'mackerel sky'; it consists of small roundish masses, disposed with more or less irregularity and connection. It is frequent in summer, and attendant on warm and dry weather. *Cirro-stratus* appears to result from the subsidence of the fibres of cirrus to a horizontal position, at the same time that they approach each other laterally. The form and relative position when seen in the distance frequently give the idea of shoals of fish. The tendency of *cumulo-stratus* is to spread, settle down into the *nimbus*, and finally fall as rain.

The height of clouds varies greatly, being much higher in summer than winter. Gay-Lussac, in his balloon ascent, at a height of 7,650 yards, observed cirrus clouds above him, which appeared still to be at a considerable height. In Ethiopia M. d'Abbadie observed storm-clouds whose height was only 230 yards above the ground.

In order to explain the suspension of clouds in the atmosphere Halley first put forth the hypothesis of *vesicular vapours*. He supposed that clouds are formed of an infinity of extremely minute vesicles, hollow, like soap bubbles filled with air, which is hotter than the surrounding air; so that these vesicles float in the air like so many small balloons. This theory has at present many opponents, who assume that clouds and fogs consist of extremely minute droplets of water, which are retained in the atmosphere by the ascensional force of currents of hot air, just as light powders are raised by the wind. Ordinarily, clouds do not appear to descend, but this absence of downward motion is only apparent. In fact, clouds do usually fall slowly, but then the lower part is continually dissipated on coming in contact with the lower and more heated layers: at the same time the upper part is always increasing from the condensation of new vapours, so that from these two actions clouds appear to retain the same height. A cloud, indeed, is not

something fixed and unchanging; it exists only in its formation and in its cessation; it is not a product, but a process.

290. **Formation of clouds.**—Many causes may concur in the formation of clouds.

I. The low temperature of the higher regions of the atmosphere. For, owing to the solar radiation, vapours are constantly disengaged from the earth and from the waters, which from their elastic force and lower density rise in the atmosphere; meeting there continually colder and colder layers of air, they sink to the point of saturation, and then, condensing in extremely minute droplets, they give rise to clouds.

II. The hot and moist currents of air rising during the day undergo a gradually feebler pressure, and thus is produced an expansion (307) which is a source of cold, and produces a condensation of vapour. Hence it is that high mountains, stopping the currents of air, and forcing them to rise, are an abundant source of rain.

III. A hot, moist current of air mixing with a cold current undergoes a cooling, which brings about a condensation of the vapour. Thus the hot and moist winds of the south and south-west, mixing with the colder air of our latitudes, give rain. The winds of the north and north-east tend also, in mixing with our atmosphere, to condense the vapours; but as these winds, owing to their low temperature, are very dry, the mixture rarely attains saturation, and generally gives no rain.

291. **Rain.**—When, by the constant condensation of aqueous vapour, the individual vapour vesicles become larger and heavier, and when finally individual vesicles unite, they form regular drops, which fall as *rain*. At great heights rain drops are very small, but they increase as they fall, for, from their low temperature, they condense on their surface the aqueous vapour of the layers of air through which they fall. The quantity of rain which falls annually in any given place, or the annual rainfall, is measured by means of a *rain gauge* or *pluviometer*.

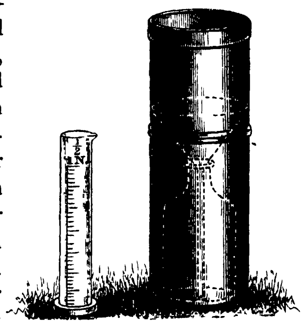


Fig. 254.

The simplest form of rain gauge consists of a funnel (fig. 254) which has a certain definite area, 12 square inches for example,

and which fits in a bottle. The rain which falls on this area is collected in the bottle, and the quantity which has fallen during the period of observation is measured by means of a graduated glass. Thus if in 24 hours the quantity collected measures 2·3 fluid ounces, this is equal to 4 cubic inches, and if the area of the funnel is 12 inches, this represents a rainfall of one-third of an inch in 24 hours. The funnel and bottle are usually enclosed in a metal cylinder which is taller than the funnel, so as to retain any snow which may fall.

Many local circumstances may affect the quantity of rain which falls in different countries; but, other things being equal, most rain falls in hot climates, for there the vaporisation is most abundant. The rainfall decreases, in fact, from the equator to the poles. At London it is 23·5 inches; at Bordeaux it is 25·8; at Madeira it is 27·7; at Havannah it is 91·2; and at St. Domingo it is 107·6. The quantity varies with the seasons; in Paris, in winter it is 4·2 inches; in spring, 6·9; in summer, 6·3; and in autumn, 4·8 inches. The heaviest annual rainfall at any place on the globe is on the Khasi Hills in Bengal, where it is 600 inches; of which 500 inches fall in seven months. On July 1, 1851, a rainfall of 25½ inches on one day was observed at Cherrapoonjee. At Kurrachee, in the north-west of India, the rainfall is only 7 inches.

Under similar circumstances the quantity of rain diminishes with the distance from the sea. Thus, if the annual rainfall is 1 in the centre of Germany, it is 1·2 in the centre of England and 1·75 on the English coasts.

An inch of rain on a square yard of surface represents a fall of 47·74 pounds, or 4·77 gallons. On an acre it corresponds to 22,622 gallons, or 100·9935 tons. 100 tons per inch per acre is a ready way of remembering this.

292. **Dew. Hoar frost.**—*Dew* is merely aqueous vapour which has condensed on bodies during the night in the form of minute globules. It is occasioned by the chilling which bodies near the surface of the earth experience in consequence of the radiation at night. Their temperature having then sunk several degrees below that of the air, it frequently happens, especially in hot seasons, that this temperature is below that at which the atmosphere is saturated. The layer of air which is immediately in contact with the chilled bodies, and which has virtually the same temperature then deposits a portion of the vapour which it contains, just as when a bottle of cold water is brought into a warm room, it be-

comes covered with moisture, owing to the condensation of aqueous vapour upon it.

According to this explanation, which was first given by Dr. Wells, all causes which promote the cooling of bodies increase the quantity of dew. These causes are the emissive power of bodies, the state of the sky, and the agitation of the air. Bodies which have a great radiating power become cool more readily, and therefore ought to condense more vapour. In fact, there is generally no deposit of dew on metals, whose radiating power is very small, especially when they are polished; while the ground, sand, glass, and plants, which have a great radiating power, become abundantly covered with dew. On some plants, for instance, not merely are droplets of dew formed, but regular layers of water.

The state of the sky also exercises a great influence on the formation of dew. If the sky is cloudless, the planetary spaces send to the earth an inappreciable quantity of heat, while the earth radiates very considerably, and therefore, becoming very much chilled, there in an abundant deposit of dew. But if there are clouds, as their temperature is far higher than that of the planetary spaces, they radiate in turn towards the earth, and, as bodies on the surface of the earth only experience a feeble chilling, no deposit of dew takes place.

Wind also influences the quantity of vapour deposited. If it is feeble, it increases it, inasmuch as it renews the air; if it is strong, it diminishes it, as it heats the bodies by contact, and thus it does not allow the air time to become cooled. Finally, the deposit of dew is more abundant according as the air is moister, for then it is nearer its point of saturation.

In those countries of the hot zones which are near the sea dew may replace rain, as in Peru and Chili; in the interior of great continents it is infrequent. In England it is equal to 1½ inches of rainfall.

Hoar frost and *rime* are nothing more than dew which has been deposited on bodies cooled below zero, and has therefore become frozen. The flocculent form which the small crystals present of which rime is formed shows that the vapours solidify directly without passing through the liquid state. Hoar frost, like dew, is formed on bodies which radiate most, such as the stalks and leaves of vegetables, and is chiefly deposited on the parts turned towards the sky.

293. **Snow. Sleet.**—*Snow* is water solidified in stellate crystals variously modified, and floating in the atmosphere. These crystals

arise from the congelation of the minute vesicles which constitute the clouds, when the temperature of the latter is below zero. They are more regular when formed in a calm atmosphere. Their form may be investigated by collecting them on a black surface, and viewing them through a strong lens. The regularity and, at the same time, variety of their forms are truly beautiful. Fig. 255 shows some of the forms as seen through a microscope from the observations of Dr. Glaisher.

It snows most in countries near the poles, or which are high above the sea level. Towards the poles, the earth is constantly covered with snow; the same is the case on high mountains, where there are perpetual snows even in equatorial countries.

One *foot* of snow may, with sufficient accuracy, be taken as equal to one *inch* of rain.

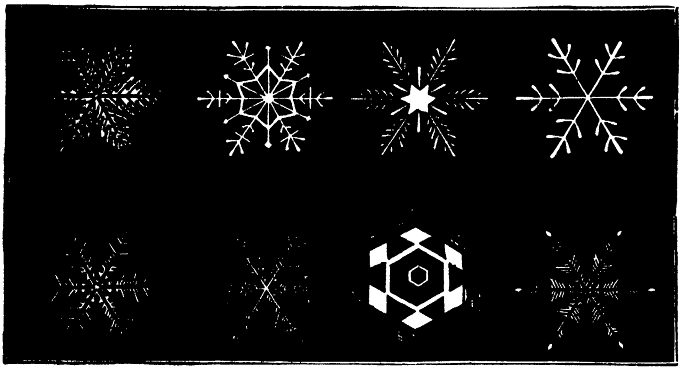


Fig. 255.

Sleet is also solidified water, and consists of small icy needles pressed together in a confused manner. Its formation is ascribed to the sudden congelation of the minute globules of the clouds in an agitated atmosphere.

294. **Hail.**—*Hail* is a mass of compact globules of ice of different sizes, which fall in the atmosphere. In our climate hail falls principally during spring and summer, and at the hottest times of the day; it rarely falls at night. The fall of hail is always preceded by a peculiar noise. Hail is generally the precursor of rain storms; it seldom accompanies them, and follows them more rarely still, especially if the rain has lasted for some time. Hail

clouds seem generally to be very low. A hailstone consists of a core of snow, which is surrounded by concentric layers of ice. Hail falls from the size of small peas to that of an egg or an orange. Their temperature is from $-0{\cdot}5°$ to $-4°$ C. The formation of hail, and more especially the great size of hailstones, have never been altogether satisfactorily accounted for. While snow sometimes falls for days together, hailstorms seldom last longer than a quarter of an hour, and they are also far less frequent. Hail is always accompanied by some electrical disturbance in the atmosphere.

ON WINDS IN GENERAL.

295. **Direction and velocity of winds.**—*Winds* are currents moving in the atmosphere with variable directions and velocities. There are eight principal directions in which they blow: *north*,

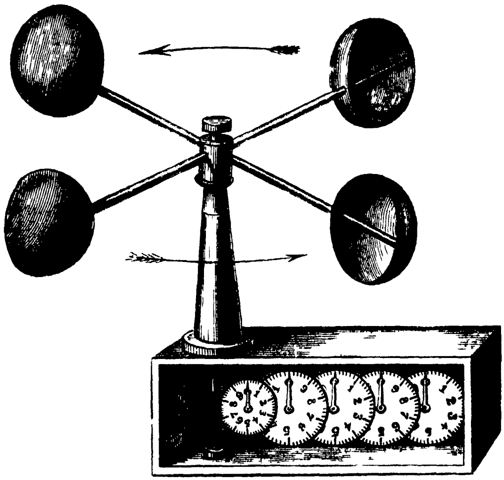


Fig. 256.

north-east, *east*, *south-east*, *south*, *south-west*, *west*, and *north-west*. Mariners further divide each of the distances between these eight directions into four others, making in all 32 directions, which are called *points* or *rhumbs*. A figure of these 32 rhumbs on a circle, in the form of a star, is known as the *mariner's card*.

The direction of the wind is determined by means of vanes, and its velocity by means of the *anemometer*. There are several forms

of this instrument. The most usual consists of a small vane with fans, which the wind turns; the velocity is deduced from the number of turns made in a given time, which is measured by means of an endless screw and wheel-work. That most commonly used in this country, and represented in fig. 256, is known as Robinson's anemometer. It consist of a metal cross with hemispheres at the ends, and fixed to an axis. The motion of this cross is transmitted by means of an endless screw to a train of wheelwork; and rom the number of turns made in a given time which is indicated by the pointers, the velocity of the wind is deduced. In our climate the mean velocity is from 18 to 20 feet in a second. With a velocity of 6 or 7 feet, the wind is moderate; with 30 or 35 feet, it is fresh; with 61 or 70 feet, it is strong; with a velocity of 85 to 90 feet, it is a tempest, and from 90 to 120 it is a hurricane. The velocity of a wind may, under appropriate circumstances, be measured by observing the time which the shadow of a cloud takes to pass over a field or any space the dimensions of which are known.

296. **Causes of winds.**—Winds are produced by a disturbance of the equilibrium in some part of the atmosphere—a disturbance always resulting from a difference in temperature between adjacent countries. Thus if the temperature of a certain extent of ground becomes higher, the air in contact with it becomes heated, it expands, and rises towards the higher regions of the atmosphere; whence it flows, producing upper currents which blow from hot to cold countries. But at the same time the equilibrium is destroyed at the surface of the earth, for the barometric pressure on the colder adjacent parts is greater than on that which has been heated, and hence a current will be produced with a velocity dependent on the difference between these pressures; thus two distinct winds will be produced, an upper one setting *outwards* from the heated region, and a lower one setting *inwards* towards it.

297. **Regular, periodical, and variable winds.**—According to the more or less constant directions in which winds blow, they may be classed as regular, periodical, and variable winds.

i. *Regular winds* are those which blow all the year through in a virtually constant direction. These winds, which are also known as the *trade winds*, are, far from the land in equatorial regions, observed to blow uninterruptedly from the north-east to the south-west in the northern hemisphere, and from the south-east to the north-west in the southern hemisphere. They prevail on the two

sides of the equator as far as 30° of latitude, and they blow in the same direction as the apparent motion of the sun; that is, from east to west.

The air above the equator, being gradually heated, rises as the sun passes round from east to west, and its place is supplied by the colder air from the north or south. The direction of the wind, however, is modified by this fact: that the velocity which this colder air has derived from the rotation of the earth—namely, the velocity of the surface of the earth at that point from which it started—is less than the velocity of the surface of the earth at the point at which it has now arrived; hence the currents acquire, in reference to the equator, the constant direction which constitutes the trade winds.

ii *Periodical winds* are those which blow regularly in the same direction, at the same seasons, and at the same hours of the day; the monsoon, simoom, and the land and sea breeze are examples of this class. The name *monsoon* is given to winds which blow for six months in one direction, and for six months in another. They are principally observed in the Red Sea and in the Arabian Gulf, in the Bay of Bengal, and in the Chinese Sea. These winds blow towards the continents in summer, and in a contrary direction in winter. The *simoom* is a hot wind which blows over the deserts of Asia and Africa, and which is characterised by its high temperature and by the sands which it raises in the atmosphere and carries along with it. During the prevalence of this wind the air is darkened, the skin feels dry, the respiration is accelerated, and a burning thirst is experienced.

This wind is known under the name of *sirocco* in Italy and Algiers, where it blows from the great desert of Sahara. During its prevalence people remain at home, the windows and doors being carefully closed. In Egypt, where it prevails from the end of April to June, it is called *kamsin*, from a word signifying *fifty*; for it lasts ordinarily 50 days; 25 before the spring equinox, and 25 after. When caravans are surprised by this wind, men cover their faces with thick cloths and camels turn their backs to the torment. The natives of Africa, in order to protect themselves from the effects of the too rapid perspiration occasioned by this wind, cover themselves with fatty substances.

The *land and sea breeze* is a wind which blows on the sea coast during the day from the sea towards the land, and during the night from the land to the sea. For during the day the land becomes

more heated than the sea, in consequence of its lower specific heat (264) and its greater conductivity, and hence, as the air above the land becomes more heated than that over the sea, it ascends and is replaced by a current of colder and denser air flowing from the sea towards the land. During the night the land cools more rapidly than the sea, and hence the same phenomenon is produced, but in a contrary direction. The sea breeze commences after sunrise, increases to three o'clock in the afternoon, decreases towards evening, and is changed into the land breeze after sunset. These winds are only perceived at a slight distance from the shores. They are regular in the tropics, but less so in our climates; and traces of them are seen as far as the coasts of Greenland. They are even observed on the shores of such inland lakes as that of Constance; and still more markedly in the great American lakes. The proximity of mountains also gives rise to periodical daily breezes. In like manner the open country is warmer during the day than an adjacent forest, while the reverse is the case at night. Hence at night there is a slight breeze from the forest towards the open, and at day from the open country towards the forest.

iii. *Variable winds* are those which blow sometimes in one direction and sometimes in another, without being subject to any law. In mean latitudes the direction of the winds is very variable; towards the poles this irregularity increases, and under the arctic zone the winds frequently blow from several points of the horizon at once. On the other hand, in approaching the torrid zone, they become more regular. The south-west wind prevails in the north of France, in England, and in Germany; in the south of France the direction inclines towards the north, and in Spain and Italy the north wind predominates.

298. **Law of the rotation of winds.**—Notwithstanding the great irregularity which characterises the direction of the winds in our latitudes, it has been ascertained that the wind has a preponderating tendency to veer round according to the sun's motion; that is, to pass from north, through north-east, east, south-east to south, and so on round in the same direction from west to north: that it often makes a complete circuit in that direction, or more than one in succession, occupying many days in doing so, but that it rarely veers, and very rarely or never makes a complete circuit in the opposite direction. For a station in the south latitude a contrary law of rotation prevails.

This law, though more or less suspected for a long time, was

first formally enunciated and explained by Dove, and is known as *Dove's law of the rotation of winds.*

298a. **Weather charts.**—A considerable advance has been made in weather forecasts by the frequent and systematic publication of *weather charts*; that is to say, maps in which the barometric pressure, the temperature, the force of the wind, &c., are expressed for considerable areas, in an exact and comprehensive manner. A careful study of such maps renders possible a forecast of the weather for a day or more in advance. We can here do little more than explain the meaning of the principal terms in use.

If lines are drawn through those places on the earth's surface where the corrected barometric height at a given time is the same, such lines are called *isobarometric lines*, or more briefly, *isobaric* lines, or *isobars.* Between any two points on the same isobar there is no difference of pressure. Isobars are usually drawn for a difference of $\frac{1}{10}$ of an inch.

If we take a horizontal line between two isobars, and at that point at which the pressure is greatest draw a perpendicular line on any suitable scale, which shall represent the *difference* in pressure between the two places, the line drawn from the top of this perpendicular to the lower isobar will form an angle with the horizontal, and the steepness of this angle is a measure of the fall in pressure between the two stations, and is called the *barometric gradient.* Gradients are usually expressed in England and America in hundredths of an inch of mercury for one degree of sixty nautical miles, and on the Continent in millimetres for the same distance. The closer are the isobars the steeper is the gradient, and the more powerful the wind; and though no exact numerical relationship can be proved to exist between the steepness of the gradient and the force of the wind, it may be mentioned that a gradient of about 6 represents a strong breeze; and a gradient of 10, or a difference in pressure of $\frac{1}{10}$ of an inch for 60 miles, is a stiff gale.

The direction of the wind is from the place of higher pressure to that of lower, and in this respect the law of Buys Ballot may be mentioned, which has been found to hold in all cases in the Northern Hemisphere, where local configuration does not come into play. *If we stand with our back to the wind the line of lower pressure is on the left hand.* For places in the Southern Hemisphere exactly the opposite law holds.

If within any area the pressure is lower, the wind blows round that area, the place of lowest pressure being on the left. The

direction of the wind is, in short, the opposite that of the hands of a watch. Such a circulation is called *cyclonic* ; it is that which is charactetisric of the West Indian hurricanes, which are known as *cyclones*. Conversely the wind blows round an area of higher pressure in the same direction as the hands of a watch ; and this circulation is called *anti-cyclonic*.

Cyclonic systems are by far the most frequent, and are characterised by steep gradients ; the air in them tends to move in towards the centre, and thence to the upper regions of the atmosphere. They bring with them, over the greater part of the region which they cover, much moisture, an abundance of cloud, and heavy rain. Anticyclonic systems have the opposite characteristics ; the gradients are slight, the wind light, and moves with the hands of a watch. The air is dry, so that there is but little cloud, and no rain. Cyclonic systems, from the dampness of the air, produce warm weather in winter, and cold, wet weather in summer. Anticyclonic systems bring our hardest frosts in winter and greatest heat in summer, as there is but little moisture in the air to temper the extremes of climate. Both systems travel over the earth's surface, the cyclones rapidly, but the anti-cyclones more slowly.

CHAPTER XIII.

SOURCES OF HEAT AND COLD.

299. **Different sources of heat.**—The following different sources of heat may be distinguished : i. the *mechanical sources*, comprising friction, percussion, and pressure ; ii. the *physical sources*—that is, solar radiation, terrestrial heat, molecular actions, changes of condition and electricity ; iii. the *chemical sources*, or molecular combinations, and more especially combustion.

MECHANICAL SOURCES.

300. **Heat due to friction.**—The friction of two bodies, one against the other, produces heat, which is greater the greater the pressure and the more rapid the motion. For example, the axles of carriage wheels, by their friction against the boxes, often become so strongly heated as to take fire. By rubbing together two pieces of ice in a vacuum below zero, Sir H. Davy partially melted them. In boring a brass cannon, Rumford found that the heat developed in the course of 2½ hours was sufficient to raise 26½ pounds of water from zero to the boiling point.

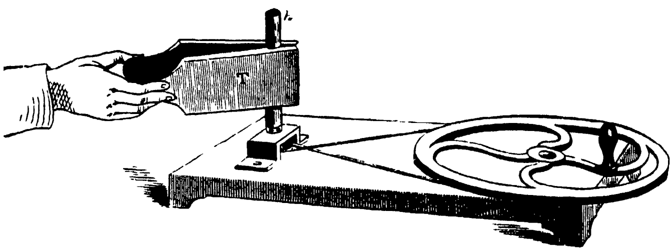


Fig. 257.

This may be well illustrated by an experiment (fig. 257) devised by Prof. Tyndall. A brass tube, *b*, closed at the bottom, about 4 inches long and less than an inch in diameter, fits on the whirling

table, having been three-quarters filled with cold water, and corked. If now it be clasped by a sort of wooden squeezer in which there are two semicircular grooves, and then be made to rotate, the heat developed by the friction is sufficient to boil the water and expel the cork by which it is closed.

The ignition of a lucifer match; the increased temperature observed in the tools used for sawing, for boring, for filing, and the like; the warmth produced by rubbing the hands together, are all instances of the production of heat by friction.

An iron drag is known to have become so heated that it hisses when water is dropped on it; to the heat produced in friction is due the hot bearings of railway carriages, which are sometimes sufficient to set fire to them.

Shooting stars, too, are probably small planetary bodies which get within the sphere of the attraction of the earth, and in falling towards it are raised to incandescence by friction against the atmosphere, and by the heat produced by the compression of the air.

301. **Heat due to pressure and percussion.**—If a body be compressed, its temperature rises according as the volume diminishes. In solids and liquids, which are but little compressible, the disengagement of heat is not great, though Joule has verified it in the case of water and of oil, which were exposed to pressures of 15 to 25 atmospheres. Similarly, when weights are laid on metallic pillars, heat is evolved, and is absorbed when they are again removed.

The production of heat by the compression of gases is easily shown by means of the *pneumatic syringe* (fig. 258). This consists

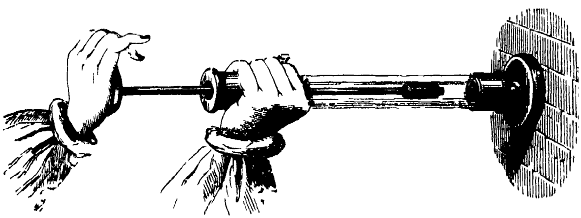


Fig 258.

of a glass tube with thick sides, closed hermetically by a leathern piston. At the bottom of this there is a cavity in which a small piece of tinder is placed. The tube being full of air the piston is suddenly plunged downwards; the air thus compressed disengages

as much heat as to ignite the tinder, which is seen to burn when the piston is rapidly withdrawn. The inflammation of the tinder in this experiment indicates a temperature of at least 300°. At the moment of compression a bright flash is observed, which was originally attributed to the high temperature of the air ; but it is simply due to the combustion of the oil which greases the piston.

Percussion is also a source of heat, as is observed in the sparks which are thrown off by horses in trotting over a hard pavement or over a flinty road, and in striking steel against a flint. In firing a shot at an iron target, a sheet of flame is frequently seen at the moment of impact; and Sir J. Whitworth has used iron shells which are exploded by the concussion on striking an iron target. A small piece of iron hammered on an anvil becomes very hot, and it is stated that in this way a skilful blacksmith can raise a piece of iron to redness.

PHYSICAL SOURCES.

302. **Solar radiation.** — The most powerful of all sources of heat is the sun.

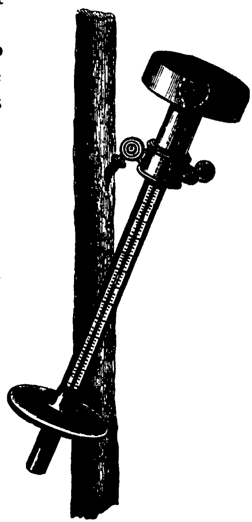


Fig. 259

Various attempts have been made to determine the quantity of heat which the sun emits. Pouillet invented an apparatus which he called a *pyrheliometer* (fig. 259). It consists of a flat metal cylinder, containing mercury. In this is introduced the bulb of a thermometer, the stem of which is protected by a piece of brass tubing. By means of a collar and screw, the instrument may be attached to a stake. The face of the cylinder which is turned to the sun is coated with lampblack; a disc is fixed to the stem the object of which is to insure that the sun's rays fall perpendicularly on the blackened face of the cylinder ; this is attained by turning the instrument so that the shadow of the cylinder exactly covers the disc. From observations made with this apparatus, Pouillet calculated that if the total quantity of heat which the earth receives from the sun in the course of a year were employed to melt ice, it would be capable of melting a layer of ice all

round the earth of 35 yards in thickness. But simple calculation shows that from the surface which the earth exposes to the solar radiation, and from the distance which separates the earth from the sun, the quantity of heat which the earth receives can only be $\frac{1}{2\ 381,000,000}$ of the total heat emitted by the sun.

Faraday estimated the average amount of heat radiated in a day on each acre of ground in the latitude of London as equal to that which would be produced by the combustion of sixty sacks of coal.

303. **Terrestrial heat.**—Our globe possesses a heat peculiar to it, which is called the *terrestrial heat.* The temperature of the earth gradually sinks from the surface to a certain depth, at which it remains constant in all seasons. It is hence concluded that the sun's heat does not penetrate below a certain internal layer, which is called the *layer of constant temperature* : the depth of this layer below the earth's surface varies, of course, in different parts of the globe ; at Paris it is about thirty yards, and the temperature is constant at 11·8° C.

Below the layer of constant temperature, the temperature is observed to increase, on the average, 1° C. for every 90 feet. This increase has been verified in mines and artesian wells (96). According to this, at a depth of 3,000 yards, the temperature of the corresponding layer would be 100°, and at a depth of 20 to 30 miles there would be a temperature sufficient to melt all substances which exist on the surface. Hot springs and volcanoes confirm the existence of this central heat.

The heat produced by the changes of condition has been already treated of in the articles *solidification* and *liquefaction* : the heat produced by electrical action will be discussed under the head of ELECTRICITY.

CHEMICAL SOURCES.

304. **Chemical combination. Combustion.**—Whenever two bodies unite, in virtue of their reciprocal affinity, this operation is known as the act of *chemical combination.* Chemical combinations are usually accompanied by a certain elevation of temperatnre. When these combinations take place slowly—as when iron oxidises in the air, and produces rust—the heat produced is imperceptible ; but if they take place rapidly, the disengagement of heat is very intense. The same quantity of heat is produced in both cases, but when evolved slowly it is dissipated as fast as it is formed, and no increase of temperature can be perceived.

Combustion is chemical combination attended with the evolution of light and heat. In the ordinary combustion in lamps, fires, candles, the carbon and hydrogen of the coal or of the oil, etc., combine with the oxygen of the air, giving rise to aqueous vapour, gases, and other volatile products which are given off as smoke. The old expression that *fire destroys everything* is incorrect. It destroys nothing; it simply puts certain elements at liberty to unite with others; it *decomposes*, but at the same time *produces*. A body in being burned is transformed, but its substance is not destroyed.

Many combustibles burn with flame. A *flame* is a gas or vapour raised to a high temperature by combustion. Its illuminating power varies with the nature of the products formed. The presence of a solid body in the flame increases the illuminating power. The flames of hydrogen and carbonic oxide gases and of alcohol are pale, because they only contain gaseous products of combustion. But the flames of candles, lamps, and coal gas have a high illuminating power. They owe this to the fact that the high temperature produced decomposes certain of the gases with the production of carbon, which, not being perfectly burned, becomes white-hot in the flame. Coal gas, when burnt in an arrangement by which it obtains an adequate supply of air, is almost entirely devoid of luminosity. A non-luminous flame may be made luminous by placing in it platinum wire or asbestos. The temperature of a flame does not depend on its illuminating power. A hydrogen flame, which is the palest of all flames, gives the greatest heat.

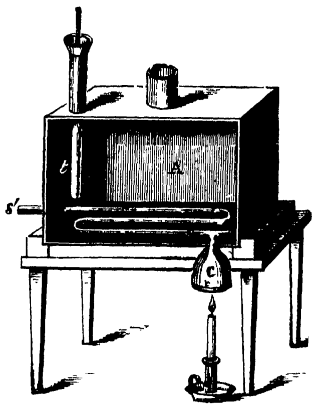


Fig. 260.

305. **Rumford's calorimeter.**—In order to determine the amount of heat which is produced by combustion, Rumford used the calorimeter depicted in fig. 260. A metal box contains a known weight of water at a known temperature; through it passes a copper worm

tube, $s s'$, which is open at one end s', and at the other ends in a funnel c. The substance whose heating effect is to be determined is placed underneath the funnel, and, having been previously weighed, is lighted. The gaseous products of combustion pass then through the worm, and, imparting their heat to the water, raise the temperature. From the weight of the water, and its increase in temperature, which is measured by the thermometer, and from the weight of the body burned, its heating effect may be determined.

By experiments with more perfect arrangements, based, however, on the same principle, the heating effect of the following substances has been determined. The numbers represent the number of pounds of water which are raised through 1°C. by the combustion of a pound of the substance, and are called the *thermal equivalents.*

Hydrogen	34,500	Phosphorus	5,700
Marsh gas	13,060	Dry turf	4,800
Petroleum	12,300	Wood	2,900
Olive oil	9,860	Carbonic oxide	2,400
Anthracite	8,460	Sulphur	2,200
Coal	7,000	Zinc	1,300
Tallow	8,000	Iron	1,181

SOURCES OF COLD.

306. **Various sources of cold.**—Besides the cold caused by the passage of a body from the solid to the liquid state, of which we have already spoken (238), cold is produced by the expansion of gases, by radiation in general, and more especially by radiation at night.

307. **Cold produced by the expansion of gases.**—We have seen that when a gas is compressed its temperature rises. The reverse of this is also the case; when a gas is rarefied a reduction of temperature ensues, because a quantity of sensible heat disappears when the gas becomes increased to a larger volume. This may be shown by placing a delicate spiral thermometer (fig. 216) under the receiver of an air-pump, and exhausting; at each stroke of the piston the needle moves in the direction of zero, and regains its original temperature when air is admitted.

Kirk invented a machine for the manufacture of ice, which depends on this property of gases. The heat developed by the compression of air is removed by a current of cold water; the vessel containing the air thus compressed and cooled being placed

in brine, the air is allowed to expand; in so doing it cools the brine so considerably as to freeze water contained in vessels placed in the brine. It is stated that by this means a ton of coals (used in working a steam engine by which the compression is effected) can produce a ton of ice.

The principle is also applied in the construction of *refrigerating rooms.* The air is compressed by what is in effect a steam condensing pump (145), and is then reduced to the temperature in the atmosphere by a current of cold water. Being next allowed to expand, the air is greatly cooled, and is made to pass into the spaces where temperature is to be reduced. By this means it is not difficult to reduce the air to a temperature 15° or more below zero. Such rooms are used for storing meat in hot weather, and also in transporting carcases from the colonies.

308. **Cold produced by radiation at night.**—During the day, the ground receives from the sun more heat than it radiates into space, and the temperature rises. The reverse is the case at night. The heat which the earth loses by radiation is no longer compensated for, and consequently a fall of temperature takes place, which is greater according as the sky is clearer, for clouds send towards the earth rays of greater intensity than those which come from the celestial spaces. In some winters it has been found that rivers have not frozen, the sky having been cloudy, although the thermometer has been for several days below —4°; while in other less severe winters the rivers freeze when the sky is clear. The emissive power exercises a great influence on the cold produced by radiation; the greater it is, the greater is the cold.

In Bengal, the cooling at night is used in manufacturing ice. Large flat vessels containing water are placed on non-conducting substances, such as straw or dry leaves. In consequence of the radiation the water freezes, even when the temperature of the surrounding air is 10° C. The same method can be applied in all cases with a clear sky. It is said that the Peruvians, in order to preserve the shoots of young plants from freezing, light great fires in their neighbourhood, the smoke of which, producing an artificial cloud, hinders the cooling produced by radiation.

Country people are in the habit of saying that it freezes more when the moon appears than when it is hidden by clouds. They are right in this; but the freezing is not, as they think, due to the influence of the moon. It is owing to the absence of clouds.

BOOK VI.

ON LIGHT.

CHAPTER I.

TRANSMISSION, VELOCITY, AND INTENSITY OF LIGHT.

309. **Theories of light.**—*Light* is the agent which, by its action on the retina, excites in us the sensation of vision. That part of physics which deals with the properties of light is known as *optics*.

In order to explain the origin of light, various hypotheses have been made, the most important of which are the *emission* or *corpuscular* theory, and the *undulatory* theory.

On the *emission* theory it is assumed that luminous bodies emit, in all directions, an imponderable substance, which consists of molecules of an extreme degree of tenuity ; these are propagated in right lines with an almost infinite velocity. Penetrating into the eye, they act on the retina (392), and produce the sensation which constitutes vision.

On the undulatory theory all bodies, as well as the celestial spaces, are filled by an extremely subtle elastic medium, which is called the *luminiferous ether*. The luminosity of a body is due to an infinitely rapid vibratory motion of its molecules, which, when communicated to the ether, is propagated in all directions in the form of spherical waves ; and this vibratory motion, being thus transmitted to the retina, calls forth the sensation of vision. The vibrations of the ether take place not in the direction of the wave, but in a plane at right angles to it. The latter are called the *transversal* vibrations. Some idea of these may be formed by shaking a rope at one end. The vibrations, or to and fro movements, of the particles of the rope, are at right angles to the length of the rope, but the onward motion of the wave's form is in the direction of the length of the rope.

On the emission theory the propagation of light is effected by a motion of *translation* of particles of light thrown out from the luminous body, as a bullet is discharged from a gun. On the undulatory theory there is no progressive motion of the particles themselves, but only of the state of disturbance which was communicated by the luminous body; it is a motion of *oscillation*, and, like the propagation of waves in water, takes place by a series of vibrations.

The luminiferous ether penetrates all bodies; it occupies the celestial spaces, and, although it presents no appreciable resistance to the motion of the denser bodies, it is possible that it hinders the motion of the smaller comets. It has been found, for example, that Encke's comet, whose period of revolution is about 3¼ years, has its period diminished by about 0·11 of a day at each successive rotation, and this diminution is ascribed by some to the resistance of the ether.

The fundamental principles of the undulatory theory were enunciated by Huyghens, and subsequently by Euler. The emission theory, principally owing to Newton's powerful support, was for long the prevalent scientific creed. The undulatory theory was adopted and advocated by Young, who showed how a large number of optical phenomena, particularly those of diffraction, were to be explained by that theory. Subsequently too, though independently of Young, Fresnel showed that the phenomena of diffraction, and also those of polarisation, are explicable on the same theory, which, since his time, has been generally accepted.

The undulatory theory not only explains the phenomena of light, but it reveals an intimate connection between these phenomena and those of heat; it shows, also, how completely analogous the phenomena of light are to those of sound, regard being had to the differences of the media in which these two classes of phenomena take place.

310. **Various sources of light.**—The various sources of light are the sun, the stars, heat, chemical combination, phosphorescence, electricity, and meteoric phenomena.

The origin of the light emitted by the sun and by the stars is unknown; it is assumed by some that the ignited envelope by which the sun is surrounded is gaseous, and at a very high temperature.

As regards the light developed by heat, Pouillet has observed that bodies begin to be luminous in the dark at a temperature of 500° to 600°; above that the light is brighter in proportion as the temperature is higher.

The luminous effects observed in many chemical combinations are due to the high temperatures produced. This is the case with the artificial lights used for illuminations; for luminous flames are nothing more than gaseous masses, containing solids heated to incandescence.

Phosphorescence is the property which a large number of substances possess of emitting light when placed under certain conditions.

Spontaneous phosphorescence is observed in certain vegetables and animals; for instance, it is very intense in the glowworm, and the brightness of their light appears to depend on their will. In tropical climates the sea is often covered with a bright phosphorescent light due to some extremely small zoophytes. These animalculæ emit a luminous matter so subtle that Quoy and Gaimard, during a voyage under the equator, having placed two in a tumbler of water, the liquid immediately became luminous throughout its entire mass.

Decaying wood, and some kinds of fish in a state of putrefaction, also exhibit this phenomenon. Certain substances, like some varieties of fluor-spar, become phosphorescent by friction; while others, such as sulphide of strontium, become luminous in the dark by having been previously exposed to the sun's rays.

Balmain's *luminous paint* depends on this property of phosphorescence.

311. **Opaque, transparent, translucent bodies. Absorption of light.**—Bodies on which a source of light falls present two distinct effects: one class, such as wood, metals, most stones, completely stop its passage through them: while others, such as air and glass, allow light to pass. The first class of bodies comprehends those which are called *opaque*, and the second the *transparent* and *translucent* bodies. The term transparent or *diaphanous* is applied to all bodies which at all transmit light; while *translucency* is usually restricted to the case of bodies through which objects cannot be distinctly seen. Polished glass may be called either transparent or diaphanous; but ground glass, oiled paper, and thin porcelain are translucent; for, while they transmit light, objects cannot be distinguished through them.

Of all bodies which transmit light, none can be said to be perfectly diaphanous; all extinguish, or *absorb*, a portion of the light which impinges on them. Even atmospheric air, which is transparent in comparison with all liquids and solids known to us, is not

perfectly transparent, as shown by many phenomena of everyday occurrence. Distant objects appear under a smaller optical angle, their colour is duller, and the contrasts of light and shade are weaker; in short, the more distant an object, the more does it appear surrounded by an opalescent veil, as is more particularly visible on distant hills. This effect of imperfect transparency of the atmosphere is known as *aerial perspective.* Again, on the tops of high mountains the number of stars visible to the naked eye is greater than in the plain; a phenomenon arising from the fact that in the former case the layer of air traversed is not so thick as in the latter case. In like manner, too, the sun appears less luminous when on the horizon, for then its rays traverse a thicker layer of air.

Just as there are no prefectly transparent substances, so, too, there are none which are quite opaque; at any rate, when the thickness is very small. Gold, which is one of the densest metals, allows an appreciable quantity of light to traverse it, when it is beaten out in the form of fine leaf.

Foucault showed that, when the object glass of a telescope is thinly silvered, the layer is so transparent that the sun can be viewed through it without danger to the eyes, since the metallic layer reflects the greater part of the heat and light; the tint appears slightly bluish, while in the case of gold it is greenish.

312. **Propagation of light.**—A *medium* is any space or substance which light can traverse, such as a vacuum, air, water, glass, etc. A medium is said to be *homogeneous* when its chemical composition and density are the same in all parts; these are conditions which are independent of each other. The atmosphere, for instance, has everywhere the same composition; but not everywhere the same density, owing to the variations in pressure and temperature, to which it is subject in various places.

Experiment shows that in *every homogeneous medium light is propagated in a right line.* For, if an opaque body is placed in the right line which joins the eye and the luminous body, the light is intercepted. In like manner we cannot receive any impression of light through a series of holes in opaque plates, superposed on each other, excepting these holes are in a straight line. The light which passes into a dark room by a small aperture leaves a luminous trace, which is visible from the light falling on the particles suspended in the atmosphere.

Light emanates from luminous bodies in all directions, for we see them equally in all positions in which we are placed round them.

Light changes its direction on meeting an object which it cannot penetrate, or when it passes from one medium to another. These phenomena will be described under the heads *reflection* and *refraction.*

313. **Luminous ray and pencil.**—To this sending out of light in all directions from a luminous body the same term radiation is applied as in the case of heat; a *luminous ray*, or *ray of light*, is the line in which light is propagated: a *luminous pencil*, or *pencil of light*, is a collection of rays from the same source. It is said to be *parallel* when it is composed of parallel rays: *divergent*, when the rays separate from each other; and *convergent*, when they tend towards the same point. Examples of these will occur in the study of mirrors and of lenses.

314. **Shadow. Penumbra.**—When light falls upon an opaque body, it cannot penetrate into the space immediately behind it, and this space is called the *shadow.*

In determining the extent and the shape of shadow projected by a body, two cases are to be distinguished; that in which the source of light is a single point, and that in which it is a body of any appreciable extent.

In the first case let L (fig. 261) be the luminous point, and M a spherical body, which causes the shadow. If an infinitely long straight line move round the sphere M, always passing through the

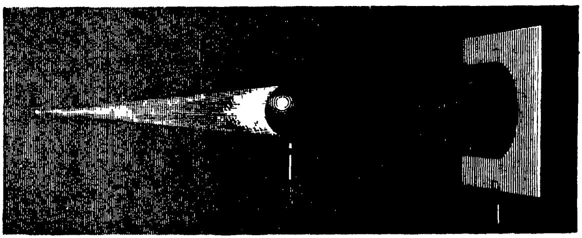


Fig. 261.

point L, this line will produce a conical surface, which, beyond the sphere, separates that portion of space which is in shadow from that which is illuminated. In the present case, on placing behind the opaque body a screen, the limit of the shadow will be sharply defined. This is not, however, usually the case, for luminous bodies have always a certain magnitude, and are not merely luminous points; the

shadow formed by a luminous point is called the *geometrical shadow.*

In the second case let L (fig. 262) be a luminous sphere, and let a straight line *bn* be drawn touching the outside of this sphere and of the sphere M. Assuming that this line moves tangentially round the two bodies, it will produce on the screen a circle, *no*, completely

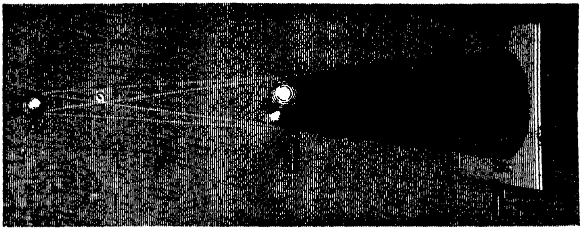


Fig. 262.

in darkness. If now a second straight line, *bm*, be drawn tangentially on the inside of the two spheres, it will produce a cone on the screen, the summit of which is at S, and the base on the screen in the circle *rm*, which is greater than the circle *no*. The circular space between the two circumferences is neither entirely in the shadow nor entirely in the light, for it is only illuminated by a part of the body L; whence arises the name *penumbra*. Under ordinary conditions, in which luminous bodies have a certain size, shadows are always surrounded by a penumbra. This decreases in intensity from the centre towards the edges; it has a greater extent the nearer the source of light is to the body illuminated, and the more distant is the screen.

315. **Velocity of light.**—Light moves with such a velocity that at the surface of the earth there is, to ordinary observation, no appreciable interval between the occurrence of any luminous phenomenon and its perception by the eye. And accordingly this velocity was first determined by means of astronomical observations. Romer, a Danish astronomer, in 1675, first deduced the velocity of light from an observation of the eclipses of Jupiter's first satellite.

Jupiter is a planet round which four *satellites* revolve, as the moon does round the earth. This first satellite, *e* (fig. 263), *suffers occultation*—that is, passes into Jupiter's shadow—at equal intervals of time, which are 42 h. 28 m. 36 s. While the earth moves in that part of its orbit nearest Jupiter, its distance from that

planet does not materially alter, and the intervals between two successive occultations of the satellite are approximately the same ; but in proportion as the earth moves away in its revolution round the sun, S, the interval between two occultations increases ; and when, at the end of six months, the earth has passed from the position T to the position *t*, a *total* retardation of 16 m. 36 s. is observed between the time at which the phenomenon is seen and that at which it is calculated to take place. But when the earth was in the position T, the sun's light reflected from the satellite *e* had to traverse the distance *e*T, while in the second position the light had to traverse the distance *et*. This distance exceeds the first by the quantity *t*T, for, from the great distance of the satellite *e*, the rays *et* and *e*T may be considered parallel. Consequently, light requires 16 m. 36 s. to travel the diameter *t*T of the terrestrial

Fig. 263.

orbit, or twice the distance of the earth from the sun, which gives for its velocity 190,000 miles per second. This has been confirmed by the results of other experiments made by different methods ; the number now generally admitted is 186,000 miles.

To give some idea of this enormous velocity, it may be remarked that a cannon ball would require more than seventeen years to traverse the distance from the earth to the sun, while light requires only 8 minutes and 18 seconds.

Notwithstanding this enormous velocity of light, the stars nearest the earth are separated from it by at least 206,265 times the distance of the sun. Consequently, the light which they send requires $3\frac{1}{4}$ years to reach us. Those stars which are only visible by means of the telescope are possibly at such a distance that thousands of years would be required for their light to reach our planetary system. We may hence form an idea of the immensity of the heavens, and how small is our globe in comparison with this infinity.

316. **Intensity of light. Law of its decrease. Photometer.** —The intensity of a source of light—that is, the energy of its illuminating power—is measured by the quantity of light which it sends on a given surface; for example, a screen a yard square. From the property which luminous rays have of diverging, this quantity of light, this intensity, decreases rapidly as the illuminated body is removed from the luminous body. It may be shown, by geometrical considerations, that the intensity of light is inversely as *the square of the distance*; that is, that when the distance of an illuminated

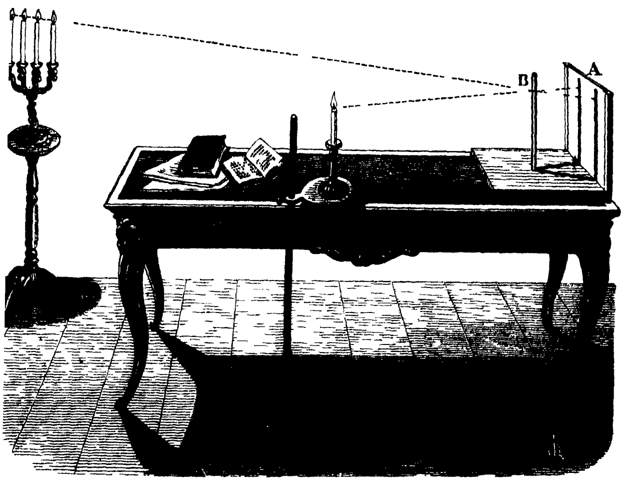


Fig 264

body from the source of light is doubled, it receives one-fourth the amount of light; at three times the distance one-ninth, and so forth.

This law may be demonstrated by the aid of the apparatus called *photometer*, from two Greek words which signify *measure of light.* One form consists of a ground glass screen A, fixed vertically on a wooden base (fig. 264). In front of this screen is an opaque rod B beyond which are the sources of light to be compared, in such a manner that the shadows of the rod form on the screen. Now it will be observed that when the two sources have the same illuminating power, the depth of the shadows is the same; but if one of the sources of light is more powerful than the other, the corresponding

shadow is deeper; and in order that the shadows be of equal intensity, the more powerful light must be removed further away.

These details being premised, the law of the decrease of light may be demonstrated as follows :—In a dark room, a candle is placed at any distance from the photometer, a yard for instance; and then, at double the distance, four of the same kind of candles are placed in the same line, in the direction of the opaque rod. The two shadows on the screen will then be found to have exactly the same depth; which shows that, at two yards' distance, four candles have no more illuminating power than one candle at a distance of one yard; from which it is concluded that each of them, at double the distance, has one quarter the illuminating power. It may also be shown in the same manner that nine candles at three yards only have the same illuminating power as one at a yard, and so forth, which proves the law.

It is important to observe that it is in consequence of the *divergence* (313) of luminous rays that light decreases as the distance increases. This decrease does not obtain in the case of parallel rays; their lustre would be the same at all distances, were it not for the absorption which takes place in even the most transparent media.

The light of the sun is 600,000 times as powerful as that of the moon; and 16,000,000,000 times as powerful as that of α *Centauri*, the third in brightness of all the stars. The moon is thus 27,000 times as bright as this star; the sun is 5,000 million times as bright as Jupiter, and 80 billion times as bright as Neptune. Its light is estimated to be equal to that of 5,500 wax candles at a distance of 1 foot. That of the full moon is about equal to that given by *one* wax candle at a distance of 126 inches.

A difference in the strength of light or shadow is perceived when the duller light is $\frac{59}{60}$ of the brightness of the other, and both are near together, especially when the shadow is moved about.

317. **Bunsen's photometer.**—This depends on the following principle :—If on a sheet of white paper a small circular grease spot be made, the transparency of this particular spot will be increased on the paper; and if a light, A, such as that of a candle, be held behind it, the spot will stand out brighter than the rest of the paper. If now another light, B, be held in front of the paper, the spot will appear darker than the rest. If this light which it throws on the paper be brighter than that of A, by moving the second light a position is found at which both the spot and the rest of the paper are equally bright. When this is the case, the brightness of the two lights

is directly as the squares of their distances from the paper. Thus, if the distances A and B are 4 and 9 inches respectively, their relative strengths will be as 16 to 81, these being the squares of 4 and 9; that is, the second light B is rather more than five times as bright as A.

This is the method in actual use for determining the illuminating powers of gas and other artificial lights. For this purpose a *standard candle*, *c*, is used, which burns a given weight of combustible in a certain time. This is fixed at one end of a graduated rule *aa* (fig. 265), while at the other end is fixed a gas jet *g* provided with a gas meter *m* by which the quantity of gas can be regulated and measured. A paper screen *b* with the grease spot is fixed to

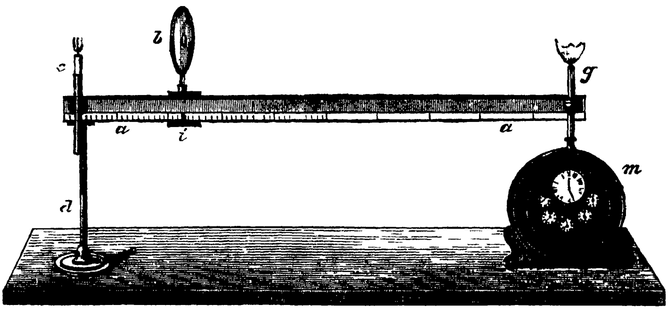


Fig. 265.

a support which moves along the rule; this position is shown by the index *i* attached to the support. By trial a position is found for it at which the grease spot just disappears; the paper is then equally illuminated on both sides, and it only remains to read off the distances of the two lights and make the calculation in the manner described above.

Thus the scale is divided into 100 parts, and suppose the screen is at 20 divisions from the standard candle when the grease spot disappears, the gas being thus at a distance of 80 divisions. This being so, this particular gas flame has sixteen times the illuminating power of the candle, and is spoken of as having a *sixteen-candle power*.

CHAPTER II.

REFLECTION OF LIGHT. MIRRORS.

318. **Laws of the reflection of light.**—When a ray of light meets a polished surface, it bounds off from it, changing its direc-

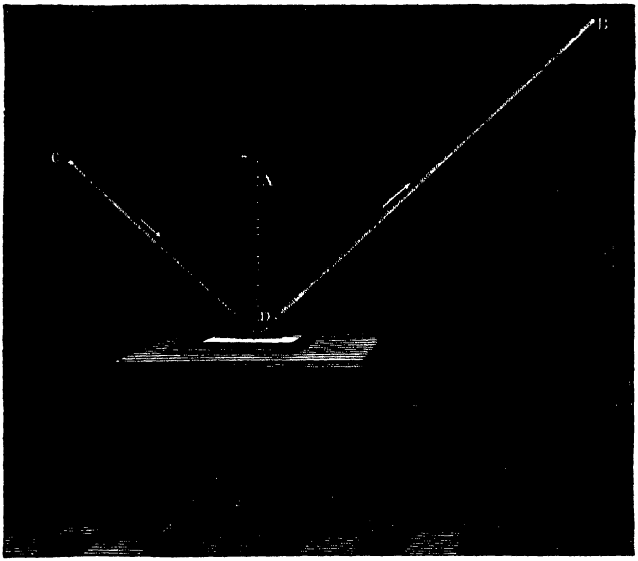


Fig. 266.

tion, and this phenomenon is termed *the reflection of light.* Thus if a pencil of the sun's rays, CD, be allowed to enter through a hole in the shutter of a dark room (fig. 266), and it be received on a plane mirror, this pencil is reflected in the direction DB, and forms on the ceiling an image, the shape of which will be discussed in speaking of the camera obscura.

As in speaking of the reflection of calorific rays (215), the ray CD is the *incident ray*, BD is the *reflected ray*, and the straight line AD at right angles to the mirror is the *normal*. The angles CDA and ADB are called respectively the *angles of incidence* and the *angles of reflection*.

The reflection of light is governed by the following two laws, which, as we have seen, also prevail for heat :—

I. *The angle of reflection is equal to the angle of incidence.*

II. *The incident and the reflected ray are both in the same plane, which is perpendicular to the reflecting surface.*

First proof. The two laws may be demonstrated by the apparatus represented in fig. 267. It consists of a graduated circle in a vertical plane, supported on three levelling screws. Two brass slides, I and K, move round the circumference. They support two small tubes, *i* and *c*, directed exactly towards the centre, and intended to give passage respectively to the incident and reflected rays. On the slide I there is, moreover, a small mirror M, which can be inclined at will. The zero of the graduation is at A, and extends to 90 degrees on each side.

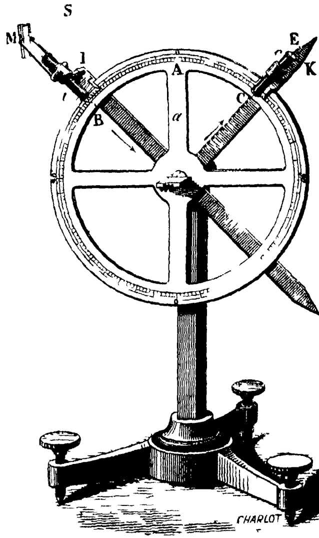


Fig 267

These details being known, the slide I having been more or less removed from zero, the mirror, M, is inclined so that a luminous ray, S, after having been reflected on this mirror, shall pass through the tube *i*, and fall upon a second mirror *m*, arranged horizontally in the centre of the circle; there the luminous ray is reflected a second time and takes the direction *m*E. The slide K is then removed to or from A, until the eye being placed at E, the reflected ray, *m*E, is seen through the tube *c*. If now the number of degrees contained in the arcs AB and AC be read off, they will be found to be

exactly equal. Hence the angles of incidence and of reflection B*ma* and *am*B, measured by their arcs, are equal, which verifies the first law.

The second law is also verified; for, in the construction of the apparatus, care is taken that the axes of the tubes *i* and *c* are in one and the same plane, parallel to that of the graduated circle, and therefore perpendicular to the surface of the small mirror *m*, and containing the normal *ma*.

In the above drawing the direction in which light is propagated is represented by arrows; the same will be the case with all optical diagrams which we shall have occasion to introduce.

319. **The reflection of light is never complete.**—The light which falls upon a body is never completely reflected; a certain portion is always extinguished—absorbed by the reflecting surface. If we represent by 100 the quantity of incident light, the reflected portion may be 50, 80, 90, according to the nature and degree of polish of the reflecting body; but it will never amount to 100.

Thus when light falls perpendicularly upon a body, the light which is reflected is $\frac{3}{5}$ of the incident light in the case of that reflected from a metal mirror, $\frac{3}{4}$ from mercury, $\frac{1}{25}$ from glass, and $\frac{1}{50}$ from water.

The best reflectors are polished metals, especially if they are white, like mercury and silver. Black bodies reflect no light. Translucent substances reflect a small quantity, and absorb more or less according to their thickness, while they transmit the remainder. This is what takes place with air, water, glass, and all transparent media.

For one and the same substance the quantity of reflected light increases not only with the degree of polish, but with the obliquity of the incident rays. For instance, if a sheet of white paper be placed before a candle, and be looked at very obliquely, an image of the flame is seen by reflection, which is not the case if the eye receives less oblique rays.

The intensity of the reflection varies with different bodies, even when the degree of polish and the angle of incidence are the same. It also varies with the nature of the medium which the light is traversing before and after reflection. Polished glass immersed in water loses a great part of its reflecting power.

320. **Irregular reflection. Diffused or scattered light.**—The reflection from the surfaces of polished bodies, the laws of which have just been stated, is called the *regular* or *specular reflection*: from a Latin word signifying mirror: but the quantity thus reflected

is less than the incident light. The light incident on an opaque body is separated, in fact, into three parts; one is reflected regularly, another *irregularly*—that is in all directions; while a third is absorbed by the reflecting body.

Thus, if in the experiment represented in fig. 266, the beam, CD, be caught on an unpolished surface instead of on a mirror, not only will it be seen in the direction DB, corresponding to regular reflection, but it will be seen in all positions in the dark room; whence it is concluded that light is reflected in all directions and under all obliquities; which is apparently contrary to the laws of reflection.

This irregularly reflected light is called *scattered* or *diffused light;* it is that which makes bodies visible; it has its origin in the structure of bodies themselves, which are never perfectly smooth, and, from their slight roughnesses, present an infinity of small facettes variously inclined, and which reflect light in all directions.

Diffused light plays an important part in the phenomena of vision. For while luminous bodies are visible of themselves, opaque bodies are only so in consequence of the diffused light which they send in all directions. Thus when we look at a piece of furniture, a table, or a flower, it is the diffused light reflected on all sides and in all directions by the object which enables us to see it, in whatever direction we may be placed in reference to the light which illuminates it. When luminous bodies only reflect light regularly, it is not them we see, but, acting like mirrors (322), they only give us the image of the luminous body whose light they send towards us. If, for example, a beam of the sun's light falls on a well-polished mirror in a dark room (fig. 266) the more perfectly the light is reflected the less visible is the mirror in the different parts of the room. The eye does not perceive the image of the mirror, but that of the sun. If the reflecting power of the mirror be diminished by sprinkling on it a light powder, the sun's image becomes feebler, but the mirror is visible from all parts of the room. Smooth polished perfectly reflecting surfaces, *if such there were*, would be invisible, and absolutely non-reflecting surfaces would also appear all equally black, and would be confounded with each other. The pencil of light seen by admitting light into a dark room is visible in consequence of the little motes floating in the air. If the sides of a glass vessel are coated with the transparent liquid, glycerine, and the electric light be allowed to fall on it, its path is at once visible; but after the lapse of some time the floating particles settle.

down and are fixed by the glycerine, and, as Tyndall has shown, the electric light now traverses the space without being seen. This may be illustrated by the following simple experiment. A beam of light admitted through a hole in the shutter of a dark room is directed upon a mirror from which it is reflected into a large wide-mouthed glass jar. If some smoke has been produced in the jar by dropping a piece of lighted touch paper in it, the whole space inside is luminous, which is not the case when the jar contains ordinary air. Two bodies, one white and the other black, placed in darkness, are quite invisible, for that which is white, not receiving any light, can reflect none.

In the case of scattered reflection the actual lustre or brightness of a luminous surface is only a fraction of the light which falls upon it, and depends on the nature of the surface. If we call the incident light 100, we have for the brightness of freshly fallen snow 78, white paper 70, white sandstone 24, porphyry 11, and ordinary earth 8.

It is the diffused light reflected by the solid particles diffused in the air, by the clouds, by the ground, which illuminates our rooms and all bodies not directly exposed to the sun's rays; and the more diffused light a body sends towards us, the more precisely can we distinguish it. From the inside of our rooms we well see external objects, for they are powerfully illuminated; but from the outside we only see confusedly the objects in the interior of apartments, for they receive but little light. If the atmosphere were perfectly transparent there would be complete darkness immediately after the sun had set; but before sunrise, as well as before sunset, there is a considerable amount of light spread over the earth's surface. This is due to the fact that the upper layers of the air diffuse the light which they receive before sunrise and sunset, and thus give rise to the phenomenon known as *twilight*. On lofty mountain summits, where a considerable part of the atmosphere is below the level, the direct rays of the sun are painfully intense, and the sky is by contrast dark.

321. **Direction in which we see bodies.**—Whenever a pencil of light passes in a straight line from a body to our eye, we see it exactly as it is; but if in consequence of reflection, or any other cause, the pencil of light is deviated in its route, if it ceases to come to us in a straight line, we no longer see the body in its proper place, but *in the direction of the luminous pencil at the moment it enters the eye.* Thus if the pencil AB is deflected at B (fig 268),

and takes the direction BC, the eye does not see the point A at A, but at *a*, in the prolongation of CB.

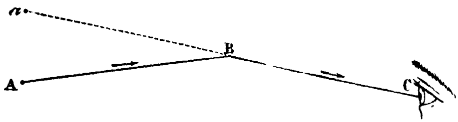


Fig. 268.

This principle is general, and though very simple, well deserves the attention of the reader, for on it are based the numerous effects of vision which mirrors and lenses present.

MIRRORS.

322. **Mirrors. Images.**—*Mirrors* are bodies with polished surfaces, which show by reflection bodies presented to them. The place at which objects appear is their *image*. According to their shape, they are divided into *plane* and *curved* mirrors.

We have an example of a plane mirror in the looking-glasses which adorn our apartments. In these mirrors it is not the glass which reflects light in sufficient quantity to give neat and well-defined images ; it is a layer of metal on the back of the glass. This layer is an *amalgam* of tin ; that is, an alloy of this metal with mercury. The glass only has the effect of giving the metal the necessary polish, and of preserving it from external agencies which tend to tarnish it.

Metal mirrors are also constructed of gold, silver, steel, tin. They all have the defect of tarnishing on contact with the air. The first mirror was doubtless the surface of clear water. The mirror of liquid mercury is often used by astronomers in observing the altitudes of heavenly bodies. Those of metal appear to be of high antiquity, for mention is made in Exodus of a bronze ewer made by Moses with the mirrors offered him by the Israelitish women.

323. **Formation of images in plane mirrors.**—*Plane mirrors* are those whose surface is plane. To understand the formation of images in these mirrors, let us first consider the case in which a very small object is placed in front of such a mirror; for instance, the flame of a candle (fig. 269). A divergent pencil of light emitted by this flame and falling on the mirror is reflected there, as shown in fig. 269. But it follows, from the laws of reflection, that each ray of this pencil retains, in reference to the mirror,

the same obliquity as it had before; whence it follows that the reflected rays have the same divergence in reference to each other as the incident rays. Hence if we imagine the reflected pencil prolonged behind the mirror, all the rays composing it will coincide in the same point. But as we always see objects in the direction which the rays of light have when they reach us (321), it follows that the eye, which receives the reflected pencil, should see the flame of the candle just in the place where the prolongation of these reflected rays coincide. There, in fact, is produced the image of this flame as seen in fig. 269.

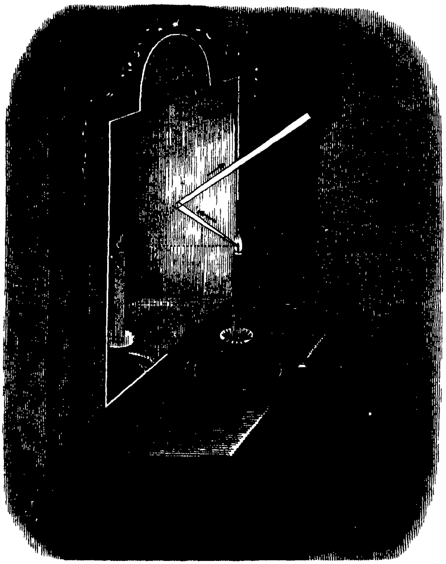


Fig. 269

If now, instead of supposing a very small object placed in front of the mirror, we consider a body of any dimensions, we need do no more than apply to each of its parts what has been said in reference to a single luminous point in order to understand the formation of its image; for instance, in fig. 270, which represents a person in front of a mirror, the rays from the forehead are reflected from the mirror and return to the eye, producing an image of the forehead. In like manner the rays from the chin being reflected from the mirror, reach the eye as if they proceeded from the chin of the image, and so on with all parts of the face; hence the illusion which makes us see our image on the other side of the mirror.

324. **Nature of the images in plane mirrors. Real and virtual images.**—If we raise the right hand, when looking in a mirror, it is the left which seems raised in the mirror; and if we

raise the left hand the right seems raised. We should falsely express this transposition of the parts of the image in reference to the object if we merely said that the image was reversed; if it were nothing else than the object reversed, in raising the right hand the image should also raise the right hand, while it really is the left which is raised.

This special equality which exists between an object and its image is expressed by saying that the image is *symmetrical* in reference to the object; that is, that any point of the image is arranged behind the mirror in identically the same manner as the

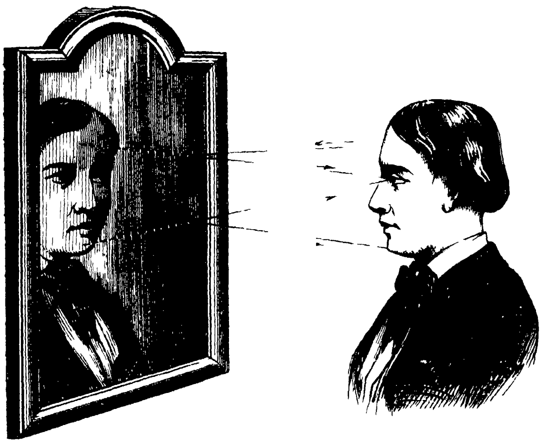


Fig. 270.

corresponding point of the object in front. For it may be shown by geometrical considerations that these two points are equidistant from the mirror, and on the same right line, which is at right angles to the surface. From the respective distance and position of the different parts of the object and of its image, it is concluded that the latter is of the same magnitude as it, and equidistant from the mirror.

Lastly, images formed in plane mirrors are *virtual*; by which we mean, that they have no real existence, and are only an illusion of the eyes. For in fig. 269 as well as in fig. 270 the light, as it does not pass behind the mirror, cannot form any image there, and that

which we see has no existence; this is expressed by the word *virtual* as opposed to *actual* or *real.* Virtual images are only an optical illusion; but we shall soon see that, in concave mirrors and in lenses, *real* images are produced which can be received on screens; this is a criterion by which they are distinguished from virtual images.

325. **Multiple images formed by glass mirrors.**—Metallic mirrors which have but one reflecting surface only give one image; this is not the case with glass mirrors, the two surfaces of which reflect, though to an unequal extent. For if we apply any object—the point of a pencil, for instance—against a thick piece of polished glass, at first when it is looked at obliquely a very feeble image is seen in contact with it; then, beyond it, another and far more intense one. The first image is due to the light reflected from the front surface of the plate—that is, on the glass itself; while the second is due to the light which, penetrating into the glass, is reflected from the layer of metal by which the hinder face is covered. The difference in brightness of the two images is readily explained; glass being very transparent, only a small quantity of light is reflected from the first face of the mirror, which gives the least intense image; while the greater part of the incident light passing into the mass is reflected from the surface of the metal, and gives the brightest image.

The above experiment furnishes a simple means of measuring the thickness of a glass mirror. For the brighter image should appear behind the layer of metal at the same distance as the point of the pencil in front; and it follows thence, that the distance between the point of the pencil and the point of its image is double the thickness of the mirror. If this distance seems to be the eighth of an inch, it will be concluded that the real thickness is $\frac{1}{16}$ of an inch.

The double reflection from mirrors is prejudicial to the sharpness of images, so that, in scientific observations, mirrors of metal are usually preferred to glass ones.

326. **Reflection from transparent bodies.**—We have seen that glass, notwithstanding its transparency, reflects a sufficient amount of light to give images which, though feeble, are distinct. The same is the case with water and other transparent liquids. Thus on the borders of a pool, we see formed in the water the reversed image of objects on the opposite bank. We say *reversed* image, so as to express the appearance; but more strictly we should say

symmetrical, from what has been before said (324). A highly varnished picture is a mirror, and, if placed so as to reflect the light, the varnish prevents spectators from seeing the subject of the picture.

Fig. 271 represents the phenomena of reflection from the surface of water; it shows how the reflected rays, reaching the eye in an upward direction, reproduce the image of objects situated above the water, just as they would if reflected from a horizontal mirror.

Fig. 271.

327. **Multiple images in parallel or inclined glass mirrors.**—When a source of light is placed between two plane parallel mirrors, we observe a series of images the brightness of which gradually decreases.

These images are due to successive reflections on the two mirrors. Thus, let M and N (fig. 272) be the sections of the two mirrors, A a luminous body, and o the eye of the observer. This latter receives the rays which come directly from the object A, and in addition the following pencils : i. the ray Abo which after a single reflection gives the first image a ; ii. the ray Acdo which after two reflections furnishes the second image a'' ; iii. the ray A$efgo$ which is reflected three times, and produces a third image a', and so on for rays which undergo four, five, or six reflections. The number of images is theoretically infinite, but in practice it is limited ; for as light is never

completely reflected at each incidence (319) the images successively lose a portion of their lustre and at last disappear entirely.

In order not to complicate the figure, only those rays are given which fall at first on the mirror M ; but the same construction should be repeated for the mirror N, which would double the number of images.

If the mirrors, instead of being parallel, make an angle with each other, the number of images is less. Fig. 273 represents the case in which they form a right angle ; three images, *a*, *a′*, *a″*, are then formed ; the first two after a single reflection ; the

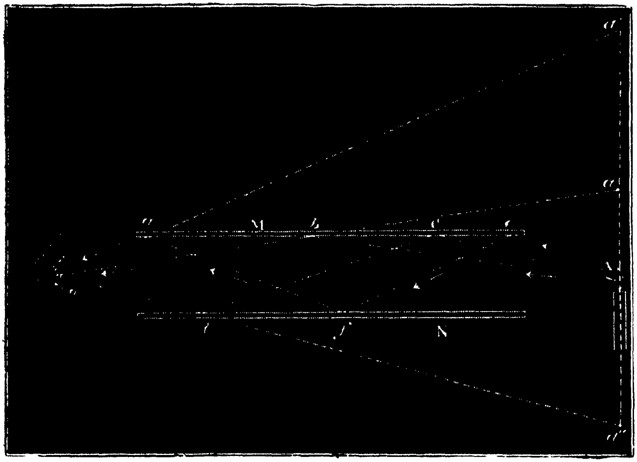


Fig. 272.

third after two reflections. If the angle is one of 60 degrees there are five images.

The *Kaleidoscope*, invented by Sir D. Brewster, depends on this property of inclined mirrors. It consists of a tube, in which are three mirrors inclined at 60° ; one end of the tube is closed by a piece of ground glass, and the other by a cap provided with an aperture. Small irregular pieces of coloured glass are placed at one end between the ground glass and another glass disc, and on looking through the aperture, the other end being held towards the light, the objects and their images are seen arranged in beautiful symmetrical forms ; by turning the tube, an almost endless variety

of these shapes is obtained. The *Debuscope*, which has two mirrors at an angle of 60°, is also an application of this property of reflection from inclined mirrors.

CURVED MIRRORS.

328. **Concave mirrors.**—There are many kinds of curved mirrors ; those most in use are called *spherical mirrors*, from their curvature being that of a sphere, They may be either of metal or of glass, and are either *concave* or *convex*, according as the reflection is from the internal or the external face of the mirror. For experiments on a small scale the phenomena of concave mirrors may be shown by means of a curved watchglass which is blackened on

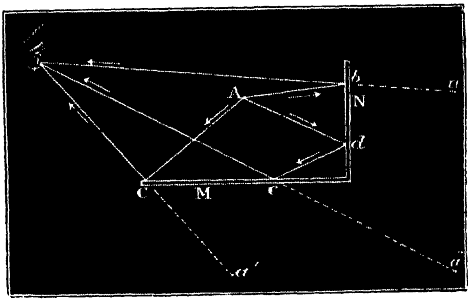


Fig. 273.

the convex side ; in like manner the phenomena of convex mirrors may be shown by one which is blackened on the concave side.

To facilitate the study of concave mirrors we will first consider what is called a *section* ; that is, the figure obtained by cutting it into two equal parts. Let MN (fig. 274) be the section of a spherical mirror, and C the centre of the corresponding sphere. In reference to the sphere this point is called the *centre of curvature* ; the point A is the *centre of the figure*. The right line, ACX, which passes through A and C, is the *principal axis* of the mirror ; any right line *i*C*d*, which simply passes through the centre C, and not through the centre of figure A, is a *secondary* axis. The angle MCN, formed by joining the centre and extremities of the mirror, is the *aperture*. A *principal* or *meridional section* is any section made by a plane through its principal axis. In speaking of mirrors those lines alone will be considered which lie in the same principal

section. There is only one principal axis, but the number of secondary axes is unlimited.

The manner in which light is reflected from curved mirrors is easily deduced from the laws of reflection from plane mirrors, by considering the surface of the former as made up of an infinitude of extremely small plane surfaces, all equally inclined to each other so as to form a regular spherical surface. Accordingly, on this hypothesis, when a ray of light falls upon any point whatever of a curved mirror, it is really from a small plane mirror that it is reflected; the reflection takes place then in accordance with the laws already laid down (318).

329. **Focus of concave mirrors.**—The small facettes, of which we have assumed concave mirrors to be made up, being all inclined towards a common centre, which is the centre of curvature of the mirror, it follows from this obliquity that the rays reflected by these mirrors tend to unite in a single point, which is called the *focus*, as we have already seen in the case of heat (216).

To explain this property of curved mirrors, let SI be a ray falling upon such a mirror parallel to the axis AX (fig. 274). From the hypothesis assumed above, the reflection takes place at I, on an infinitely small plane mirror. It can be shown by geometrical considerations that the

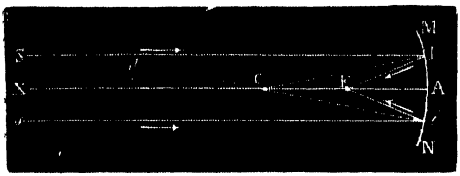


Fig. 274.

perpendicular to this small mirror is represented by the right line CI from the centre C to the point I. Hence the angle SIC represents the angle of incidence, and if we imagine, on the other side of the perpendicular, a straight line IF, which makes with CI an angle FIC, equal to CIS, this straight line will be in the direction of the reflected ray.

But when the incident rays are parallel to the axis of the mirror, as in the above example, it may be proved by geometrical considerations that the point F, where the luminous ray cuts the axes, is the middle of AC; that is, it is equidistant from the centre and the mirror. This property being common to all rays parallel to the axis, it follows that, after reflection, these rays will all coincide in the same focus, F, as shown in the figure.

The focus described above, namely, that formed at an equal distance from the centre and from the mirror, is called the *principal focus* ; it is produced whenever the rays falling on the mirror are parallel to its axis. An example of this is seen in fig. 275, which represents a pencil of sun light falling upon a concave mirror. If a small ground-glass screen be placed where the reflected rays tend to concentrate themselves, a very luminous point, or rather small circle, will appear, which is the principal focus.

330. **Conjugate focus.**—In the foregoing examples we have considered the case of pencils of parallel rays, which presupposes

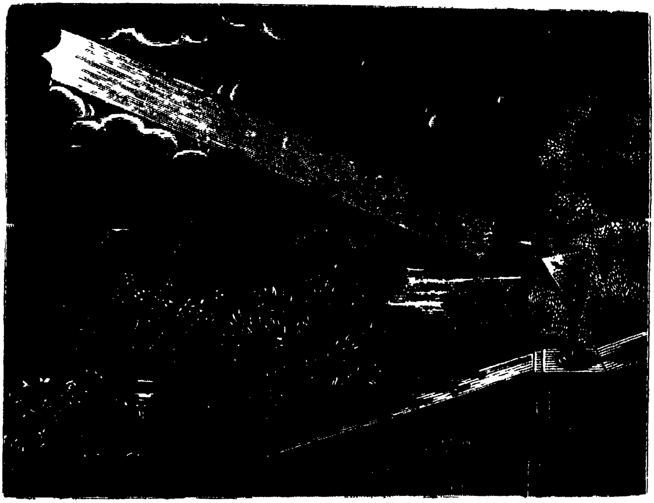


Fig. 275.

a luminous object at an infinite, or at all events a very great distance. Let us now consider the case in which, the source of light being at a small distance, the rays falling on the mirror are divergent, as shown in fig. 276. Here the reflected rays are converged, but less so than in figs. 274 and 275, which results from the divergence of the light in arriving on the mirror. Hence the point where the reflected rays coincide is more distant; instead of being at F, equidistant from the mirror and the centre, it is at *b*, between the points F and C. This point, *b*, where the rays coincide, is also a focus. To distinguish it from the principal focus F, it is

called the *conjugate focus*, from a Latin word meaning *connected*; for there is this connection between the position of the luminous point B and that of the focus, that when the luminous object is at B, the rays form their focus at *b*; and that, conversely, if the luminous object is removed to *b*, the reflected rays form their focus at B.

We have seen that there is only a single position for the principal focus, which is at an equal distance from the centre and from the mirror: this is not the case with the conjugate focus, the position of which is very variable. For suppose that in fig. 276 the candle is removed away from the mirror, as the incident rays make then gradually increasing angles of incidence with the perpendicular, *cm*, the angles of reflection, *cmb*, increase too, and the focus *b* approaches the point F, with which it will ultimately

Fig. 276

coincide, when the candle is so far distant that the incident rays are virtually parallel.

If, on the contrary, the candle is brought nearer the mirror, the rays falling upon it make angles with the perpendicular, *cm*, which are gradually smaller; the angles of reflection, *cmb*, decrease also. Hence the rays sent by the mirror coincide at gradually greater distances, the focus *b* abvances towards the centre *c*; and if the candle comes nearer the point, so as to coincide with it, the same will be case with the focus *b*; so that the candle and its image will coincide at *c*.

Lastly, if the candle, always approaching the mirror, passes between the centre of curvature and the principal focus F, the conjugate focus *b*, continually removing from the mirror, passes on the other side of the centre, and is formed at a greater distance the nearer the luminous body is to the principal focus;

if the candle coincides with this latter point, the conjugate focus forms at an infinite distance—that is, the reflected rays become parallel.

These different effects of reflection are a consequence of the constant equality between the angle of incidence and the angle of reflection. They are very simply verified by placing in a dark room a candle in front of a concave mirror successively in various positions, and then ascertaining by trial where the luminous focus is formed on a small screen of paper held in the hand, and which is brought nearer to or away from the mirror.

331. **Virtual focus.**—After having described the different positions of the point in which the rays reflected by a concave mirror coincide, when the luminous body is either beyond or in the principal focus, we have to inquire what becomes of these same rays when

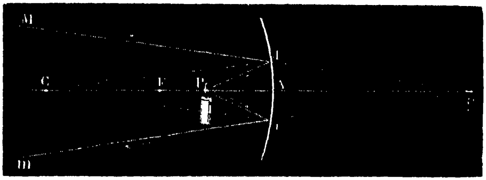


Fig. 277.

the source of light is at any point P, which is nearer the mirror than the principal focus (fig. 277). In this case the reflected rays form a diverging pencil, and cannot therefore produce any focus in front of the mirror; but as regards the eye which receives them, they produce exactly the same effect as in plane mirrors (323); that is, the eye receives the same impression from the reflected rays IM and *im* as if the candle were placed behind the mirror at the point *p*, where the prolongations of these rays coincide. Hence the image of the candle is seen at *p*, but as the light does not penetrate behind the mirror, this image does not really exist: hence the focus which seems to form at *p* is called the *virtual* focus, the expression being understood in the same sense as in plane mirrors.

332. **Formation of images in concave mirrors.**—Concave mirrors give rise to two kinds of images, real and virtual. Their formation is readily understood after what has been said respecting the conjugate and the virtual focus. We may, however, remark that when a luminous or illuminated point is situated on the principal axis of a mirror, its focus, real or virtual, is always formed on this axis. This is the case in figs. 276 and 277; but if the luminous point is on a secondary axis, the focus is formed on this axis.

Thus, if in fig. 274 a candle were placed at *d*, on the secondary axis *i*C*d*, the reflected rays would form their focus on the line C*i*. That being admitted, let us see how images are formed in concave mirrors.

Real image.—If a person places himself at a certain distance in front of a concave mirror, he no longer sees himself erect and of the ordinary size, as in plane mirrors, but reversed, and much smaller, as shown in fig. 278. To this image the name ***real image*** is given, to express that it is not an illusion, as that seen in plane mirrors, but that it has a real existence. For it may be received on a screen. If the mirror be placed in front of a brightly lighted

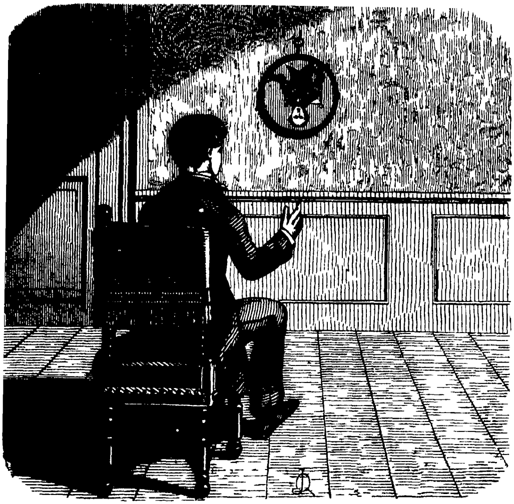


Fig 278.

object, as, for instance, before a building on which the sun is shining, and a person places himself a little on one side, holding a small white screen in the position in which the conjugate focus should be formed, the pencils from the various parts of the edifice are reflected from the mirror and fall on the screen, forming in miniature an image not less remarkable for the colour than for the fidelity of the outlines (fig. 279); it has no other defect than that of being reversed.

The formation of this image is readily explained. For from what has been said in reference to conjugate foci (330) each point

of the image is the conjugate focus of the corresponding point of the illuminated body, and is on the same secondary axis. But as all the secondary axes from the various points of this body cross in the centre of curvature of the mirror, it follows, as shown in the figure, that the rays from the higher parts of the body converge towards the lower part of the image, and that conversely rays from the foot unite on the higher parts of this same image, which explains how it is the latter is reversed.

It is to be observed that the real image in concave mirrors

Fig. 279.

is not always smaller than the object illuminated, as is the case in the above two figures; it may also be larger. This is the case when, the object being placed between the principal focus and the centre of curvature, its image is formed outside the latter, and it is then larger the greater the distance at which it is formed.

Virtual image.—Fig. 278 shows how, when a person is placed at a certain distance in front of a concave mirror, he sees himself smaller and reversed. If he comes nearer, there is a point at which no image is seen. This is the case when he is between the centre and the principal focus, for the image is then formed

behind the observer. If he is in the principal focus itself, there is no image. For we know (330) that the luminous rays proceeding from this focus, after being reflected from a concave mirror, produce a parallel luminous pencil: hence, as the rays coincide neither behind nor in front of the mirror, they cannot give rise to any image. But, approaching the mirror, the image suddenly reappears, and, instead of being smaller and reversed as it was, is now erect and much enlarged, as in fig. 280. This is the *virtual image.*

Fig. 280.

To account for the formation of this image, we must recall what has been said about the virtual focus (331): First that it is only formed as long as the luminous or illuminated object is between the principal focus and the mirror; second, that

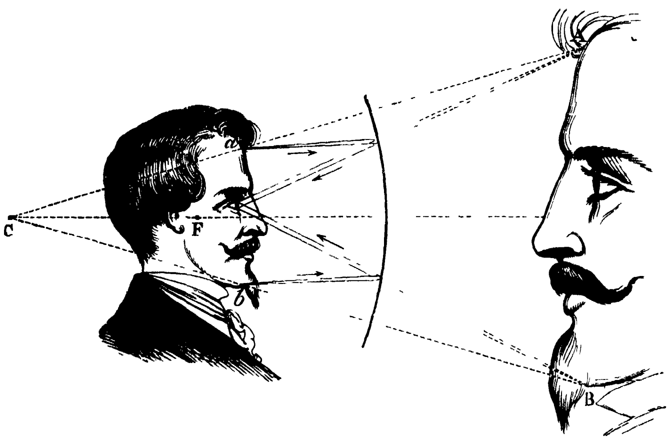


Fig. 281.

the virtual focus, or, what is the same thing, the virtual image of any point of the object, is behind the mirror on the secondary

axis which passes through this point. Hence, the head of the observer being placed between the mirror and the principal focus (fig. 281), all rays from any point, *a*, of the face return to the eye after reflection, as if they proceeded from the point *a*, where the prolongations of the reflected rays coincide on the secondary axis, C*a*A. In like manner, rays from the point *b* return to the eye, as if they were emitted from the point B, which is on the prolongation of the secondary axis, C*b*B. The eye sees, therefore, at AB, an erect and enlarged image.

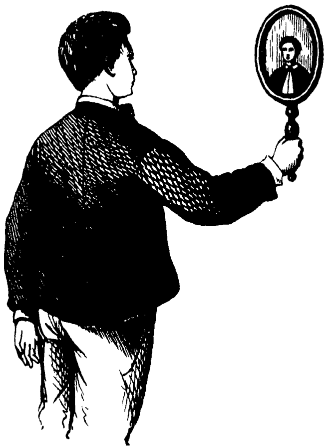


Fig. 282.

333. **Formation of images in convex mirrors.**—We have already seen that convex mirrors are spherical mirrors, which reflect light from their external surface—that is, on the bulbed side. Whatever the distance of a luminous or illuminated object placed in front of these mirrors, we never obtain any other than a virtual image situated on the other side of the mirror, always erect, and smaller than the object. This may be verified by looking in a mirror of this kind as represented in fig. 282. The formation of this image can be easily explained by an inspection of fig. 283. It is here smaller than the object, for it is nearer than the latter to the point where the secondary axes coincide, while the reverse is the case with the formation of the virtual image in the concave mirrors.

The images of objects seen in concave or convex mirrors appear smaller or larger, but otherwise similar geometrically, except in the case where some parts of a body are nearer the mirror than others. The distortion of features observed on looking into a spherical garden mirror is more marked the nearer we are to the glass. Objects seen in *cylindrical* or *conical* mirrors appear ludicrously distorted. From the laws of reflection the shape of such a distorted figure can be geometrically constructed. In like manner distorted images of objects can be constructed which, when viewed

in such mirrors, appear in their true proportions. They are called *anamorphoses*.

334. **Applications of mirrors.**—The applications of plane mirrors in domestic economy are well known. Mirrors are also frequently used in physical apparatus for sending light in a certain direction. The sun's light can only be sent in a constant direction by making the mirror movable. It must have a motion which compensates for the continual change in the direction of the rays produced by the apparent daily motion of the sun. This result is obtained by means of a clockwork motion, to which the mirror is fixed, and which causes it to follow the course of the sun. Such an apparatus is called a *heliostat*. The reflection of light is also used to measure the angles of crystals by means of the instruments known as *reflecting goniometers*.

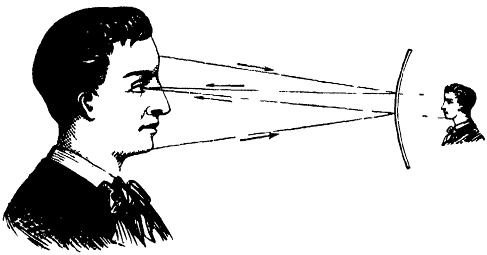


Fig. 283.

They have been employed for burning mirrors, and are used in telescopes, as they only give one image. They also serve as reflectors, for conveying light to great distances, by placing a luminous object in their principal focus. For this purpose, parabolic mirrors are preferable.

The reflection of light from mirrors has been applied by Sir H. Mance in signalling at great distances by means of the sun's light with an instrument called the *heliograph*.

The apparatus consists essentially of a mirror about 4 inches in diameter mounted on a tripod, and provided with suitable adjustments, so that the sun's light can be received upon it and reflected to a distant station. An observer then can see through a telescope the reflection of the sun's rays as a spot of light. The mirror has an adjustment by which it can be made to follow the sun in its apparent motion. There is also a lever key by which the signaller can deflect the mirror through a very small angle either to the right or left, and thus the observer at a distant station sees corresponding flashes to the right or left. Under the subject of Telegraphy it will be seen how these alternate motions can be used to form an alphabet.

The heliograph proved of essential service in the campaigns in Africa and Afghanistan. Instead of any special form of apparatus, an ordinary shaving mirror or hand glass is frequently used; and the proper inclination having been given so as to send the sun's rays to the distant station, which is very easily effected, the signals are produced by obscuring the mirror by sliding a piece of paper over it for varying lengths of time. In this way longer or shorter flashes of light are produced, which, properly combined, form the alphabet.

Of course this mode of signalling can only be used where the sun's light is available, but it has the advantage of being cheap, simple, and portable. Signals have been sent at the rate of 12 words a minute, through distances, in very fine weather, of 40 miles.

CHAPTER III.

REFRACTION OF LIGHT.

335. **Phenomenon of refraction.**—When a ray of light passes more or less obliquely from one transparent medium into another—for instance, from air into water, or from air into glass—it undergoes a deflection from the straight line in which it proceeds, as seen in fig. 284, which represents a ray of light passing from air into water. This change in direction is called *refraction*, from a Latin word meaning *broken*; for the ray is, in fact, broken at the point A, where it passes from the direction LA to the direction AK.

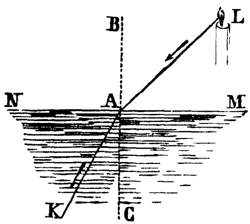


Fig. 284.

The ray LA is called again the *incident ray*; AK is the *refracted ray*; the perpendicular, BC, drawn at the point of incidence, A, of the surface, MN, which separates the two media, is called the *normal* or *perpendicular*; the angle B A L, is called the *angle of incidence*; and the angle C A K, the *angle of refraction.* If the angle of incidence is zero, that is, if the incident ray is perpendicular to the surface, the same is the case with the refracted ray, and light thus travels in a straight line—that is, is not refracted.

336. **Laws of refraction.**—When a ray of light is refracted in passing from one medium to another of a different refractive power the following laws prevail:—

I. *Whatever the obliquity of the incident ray, the ratio which the sine of the incident angle bears to the sine of the angle of refraction is constant for the same two media, but varies with different media.*

II. *The incident and the refracted ray are in the same plane, which is perpendicular to the surface separating the two media.*

These laws may be understood by reference to fig. 285, in which the ray, LA, passes from air into water. If, from the point of incidence, with a radius equal to unity, a circle be described,

and from the points, *m* and *p*, where it cuts the incident and refracted rays, perpendiculars, *mn* and *pq*, are drawn to the normal, BC, the former is called the ***sine of the angle of incidence***, and the second the ***sine of the angle of refraction***.

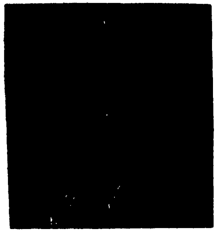


Fig. 285.

It is the ratio of these sines, these perpendiculars, which is constant; that is, *pq*, for instance, being three-quarters of *mn*, if the angle of incidence diminishes or increases, the angle of refraction does so too, but the sine of the latter will always be three-quarters of the sine of the former.

This constant ratio is called the *refractive index*, or *index of refraction*; its value varies with different transparent media. Thus from air to water it is $\frac{4}{3}$, and from air to glass $\frac{3}{2}$.

337. **Refracting substances.** — When a ray of light is refracted in passing from one medium into another, sometimes it approaches the perpendicular, forming an angle of refraction, which is less than the angle of incidence, as is the case in the above figure; sometimes, on the contrary, it is deflected away, forming an angle of refraction, which is greater than the angle of incidence. In the first case the second medium is said to be more *refringent* or *refractive* than the first, and in the second case it is less so.

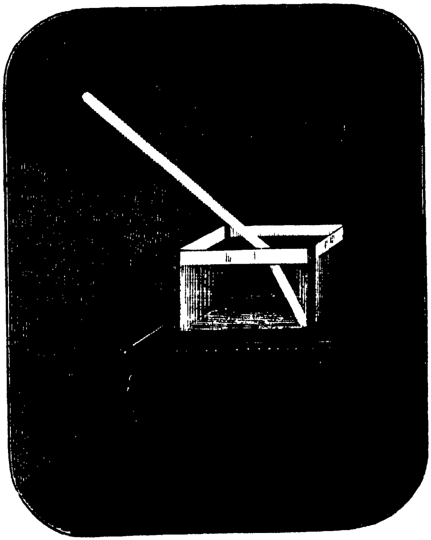


Fig. 286.

Among the most refringent bodies are water, alcohol, ether, the volatile oils, etc.

Diamond is the most refringent of all bodies. Gases are less refringent than water; their refracting power is increased by condensing them—that is, by increasing their density.

338. **Experimental proofs of refraction.**—The deviation undergone by luminous rays, on passing from one medium to another, may be demonstrated by numerous experiments. Thus, if a pencil of the sun's rays which enters through a shutter in a dark room be allowed to fall on a glass vessel containing water (fig. 286), the pencil can be very distinctly seen to be broken as it passes from air into water, especially if some light powder has been diffused through the air and the water so as to make the pencil more visible (320).

Or let a coin be placed at the bottom of an opaque vessel (fig. 287) and let the eye be placed so that the edge of the vessel just intercepts the view of the coin. If, now, without altering the position of the observer, a little water be gradually poured into the vessel, at first only the edge of the coin will be seen, then half, and finally the entire piece. Now, what has taken place here? Nothing has been changed in the position of the eye, or in that of the coin; it is the rays from the latter which have changed their direction. Those which were before intercepted by the sides of the vessel are so still; but rays which, before there was water in the vessel, passed above the observer's head, are directed towards the eye, being refracted in passing from water into air, so as to diverge from the perpendicular to the surface of the liquid, as represented in the figure.

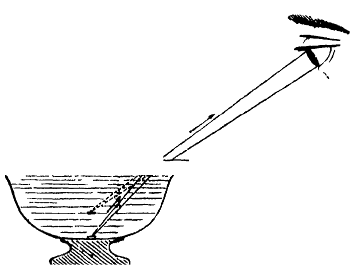


Fig. 287.

339. **Various effects of refraction.**—Refraction of light produces various phenomena, the effect of which is to deceive the eye by making us see objects in other than their true positions; thus we do not see fish in the place they actually occupy, but a little higher, as indicated by the path of the refracted ray in fig. 288. It will be understood that in consequence of the same phenomena we see the bottom of a clear river or a pond higher than it really is; we thus underestimate the depth of the water to such an extent as to be dangerous.

The same cause makes a stick half immersed in water appear

broken when it is looked at at the side; for the portion out of the water is seen in its true position, while that which is immersed

Fig 288

appears raised, from which results the appearance of the stick being broken at the surface of the liquid (fig. 289). The part of a ship or boat visible under water appears much flatter than it really is.

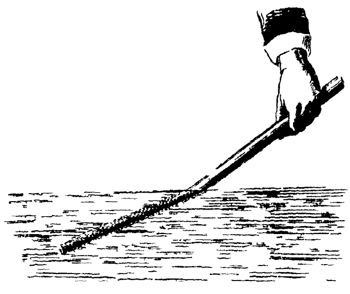


Fig 289.

In conclusion, the influence may be mentioned which refraction exerts upon the apparent rising and setting of the stars, which we can see a little before they are above the horizon, and a little after they have sunk below it. To explain this phenomenon let us suppose the atmosphere divided into layers parallel to the surface of the globe as represented in fig. 290. Owing to the pressure exerted by the upper layers upon the lower ones, the latter are more dense (132)

and therefore more refringent, for, as we have seen, the refracting power of the air increases with its density (337). The sun's rays, which penetrate the atmosphere, are always refracted in the same direction as they pass from one layer to another; hence their path, instead of being that of a straight line, will be really somewhat curved. Thus it is that, while the sun is at S, below the horizon, HH, an observer at A, on the surface of the earth, will see it raised by an amount which is generally equal to its apparent diameter. The air renders the sun visible when it is in fact below the horizon, in just the same way as the coin in fig. 287 is made visible.

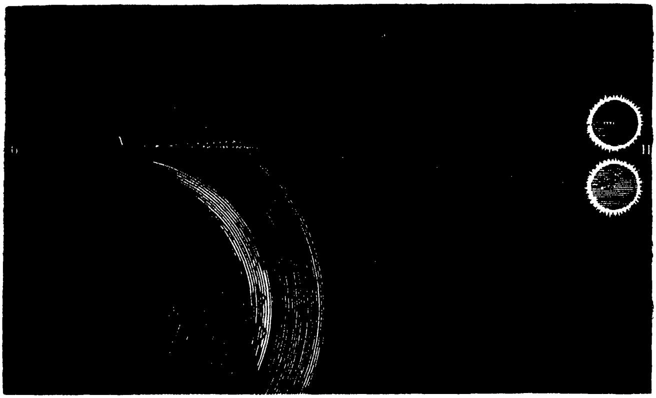


Fig. 290.

340. **Change of refraction to reflection.**—Whenever light passes from one medium into a more refringent one, from air into water for instance, there is nothing to prevent the refracted ray from approaching the perpendicular to form an angle smaller than the angle of incidence; but if, on the contrary, the second medium is less refringent than the first, in which case the refracted rays recede from the perpendicular, there is a limit to their deviation, and hence refraction may become impossible.

To get a clearer idea of this, let us imagine a hollow glass sphere half filled with water (fig. 291), and a ray of light, LA, to enter the liquid without being refracted, which is the case when it penetrates at right angles the small facette which we can always conceive to exist at the point at which it enters. This ray is

refracted at A in passing from water into air, and diverges from the normal, BAC, in the direction AR. Now, conceive the luminous body to move gradually from AC; as the angle of incidence, CAL, increases, the angle of refraction, BAR, does so too; and an angle, CAL, might acquire such a magnitude as to emerge parallel to the surface, AM, of the liquid. This angle of incidence is what corresponds to the *limit of refraction* or the *critical angle.* For, for any greater angle of incidence, the angle of refraction should exceed the angle BAM; and the light would then take below AM a direction such as A*r*. There would, however, then be no refraction, for the light, always travelling through water, does not change its medium. If the incident ray be then represented by *l*A, if we measure the two angles *l*AC and CA*r*, it will be found that they are exactly equal, which shows that at the point A the light is reflected according to the ordinary laws of reflection.

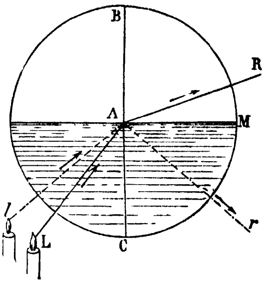


Fig. 291.

This kind of reflection at the surface which separates two media of different refracting power is called *internal reflection*: it is also called *total reflection*, for here the whole of the incident light is reflected, which is never the case in ordinary reflection, even in the best polished surfaces (319).

The phenomenon is frequently met with; thus, if a silver spoon be placed in a glass of water, and it be raised above the eye, the surface of the liquid is seen to be brighter than the polished metal, and one portion of the spoon forms an image in it as in a mirror. Similar effects are met with in aquariums. The upper surface of the liquid, when looked at from a suitable position below, gives a reflected image of the objects it contains. If a stout test tube (fig. 292) half full of mercury is placed in a vessel of water, standing on a sheet of white paper *p′ p*, so that it makes an angle

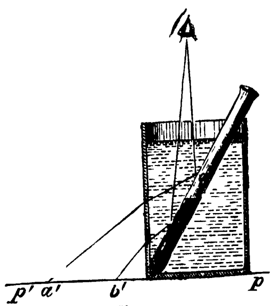


Fig. 292.

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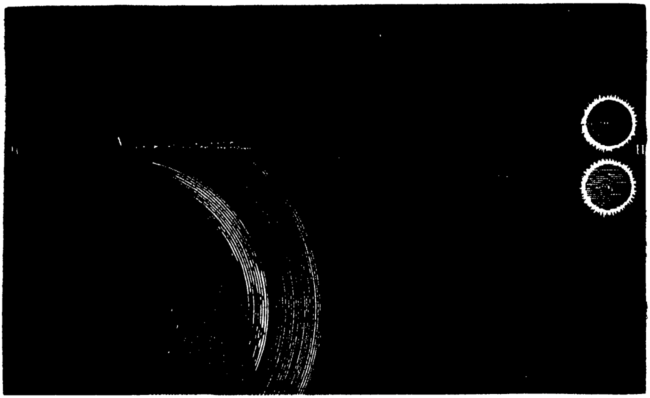

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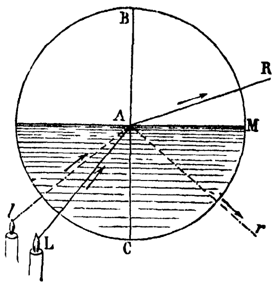

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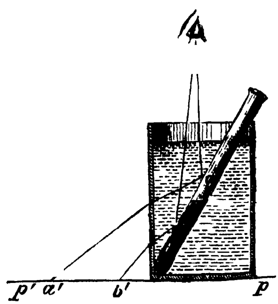


Fig. 292.

of about 60°, but at any rate over 48°, on looking at the tube from above, the rays *a′ a* reflected from the portion of the tube which contains air are far more brilliant than the rays *b′ b* reflected from that in which is the mercury.

Bubbles in water, again, glisten like pearls, and cracks in transparent bodies like strips of silver, for the oblique rays are totally reflected. The lustre of transparent bodies bounded by plane surfaces, such as the lustre of chandeliers, arises mainly from total reflection. This lustre is more frequent and more brilliant the smaller the limiting angle ; the lustre of diamond, for this reason, is the most brilliant.

If a layer of benzole be poured on water contained in a small beaker, and the bounding surface of the two liquids be looked at obliquely, it appears with the brightness of silver, for at a certain angle the rays cannot pass into the water, but are totally reflected.

Aggregations of small particles of perfectly transparent bodies separated by particles of air are themselves opaque. Thus white sand is powdered quartz ; foam is made up of transparent thin layers ; clouds, fog, snow, are accumulations of particles of transparent water or ice. In all such cases the incident light which penetrates must pass innumerable times into the air, which has a different refractive index, by which it is gradually totally absorbed. If the interstices between powdered glass are filled up with rock oil, the glass appears again transparent.

341. **Mirage.**—The *mirage* is an optical illusion by which inverted images of distant objects are seen as if below the ground, or sometimes as if in the atmosphere. This phenomenon is of most frequent occurrence in hot climates, and more especially on the sandy plains of Egypt. The ground there has often the aspect of a tranquil lake, on which are reflected trees and the surrounding villages. The phenomenon has long been known ; but Monge, who accompanied Napoleon's expedition to Egypt, was the first to give an explanation of it.

It is a phenomenon of refraction, which results from the unequal density of the different layers of the air when they are expanded by contact with the heated soil. The least dense layers are then the lowest, and a ray of light from an elevated object, A (fig. 293), traverses layers which are gradually less refracting ; for, as we have shown (337), the refracting power of a gas diminishes with lessened density. The ray continues its path, being, however, more and more bent from one layer to the other, until the angle

of incidence, which continually increases, reaches the limit at which internal reflection succeeds to refraction (340). The ray then rises at O, as seen in the figure, and undergoes a series of successive refractions, but in a direction contrary to the first, for it now passes through layers which are gradually more and more dense, and therefore more refracting. The ray then reaches the eye with the same direction as if it had proceeded from a point below the ground, and hence it gives an inverted image of the object, just as if it had been reflected at the point O from the surface of a tranquil lake.

Mariners sometimes see in the air images of the shores, or of distant vessels. This is of more infrequent occurrence, but is due to the same cause as a mirage, though in a contrary direction;

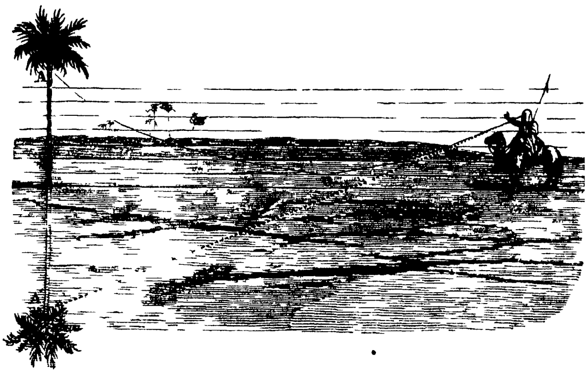


Fig 293

it only occurs when the temperature of the air is above that of the sea, for then the lower layers of the atmosphere are denser, owing to their contact with the surface of the water. The images of distant objects which are visible to us in consequence of an unusual atmospheric refraction and reflection in the air, may, when the density of the various layers changes irregularly, appear not only distorted, but even in continual motion. The best example of this is what is known as the *fata morgana*, which are often seen at Naples, Reggio, and the coasts of Sicily. There is suddenly seen in the air at a great distance ruins, columns, palaces, castles, etc., in short a multitude of objects whose appearance is continually changing. This fairy-like phenomenon depends on the fact that objects become visible which are not so in the ordinary condition of the air, and

which appear to be broken, distorted, and continually moving, because the unequally dense layers of air are in a constant state of motion. Scoresby observed several such cases in the Polar Seas. To the same class of phenomena belong the tremulous appearance of objects seen through the current of hot air arising from a chimney or a spirit lamp. It is related that in this way clandestine stills have been detected by the Revenue officers. Some of the stories of *second sight* may possibly have their origin in phenomena of this kind.

The *twinkling* or *scintillation* of the fixed stars is also to be accounted for by alterations in the direction of the motion of their light due to refraction. It has been observed that this twinkling is especially marked when the air has been dry for a long time, and more aqueous vapour begins to diffuse, by which inequalities of density are produced; thus a marked increase of the brightness of the twinkling is to seafaring people a sign of approaching rain.

The effect of the mirage may be illustrated artificially, as Dr. Wollaston showed, by looking along the side of a red-hot poker at a word or object ten or twelve feet distant. At a distance of less than three-eighths of an inch from the line of the poker an inverted image was seen, and within and without that an erect image.

A more convenient arrangement than a red-hot poker is a flat iron box closed at the top, and filled with red-hot charcoal.

Another instance may be given in that of Professor Ball, who, when on board ship, noticed the moon rise, he being in such a position that his line of sight grazed the funnel under an angle of 20′; the appearance of its light reflected from the black surface was so brilliant as to suggest the idea that the reflection was from a highly polished mirror.

CHAPTER IV.

EFFECTS OF REFRACTION THROUGH PRISMS AND THROUGH LENSES.

342. **Media with plane parallel faces.**—When a pencil of light traverses a transparent medium, three cases may be considered. First, that in which the medium is comprised between two parallel planes; second, that in which it is comprised between two plane surfaces inclined towards each other; thirdly, that in which the medium is comprised between two curved surfaces, or between a curved and a plane surface, which gives rise to similar effects.

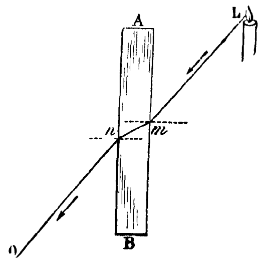


Fig. 294.

We will start with the consideration of the first case and let L*m* be a ray of light traversing a glass plate, AB, with parallel faces (fig. 294). In passing from air into glass at the point *m*, this ray approaches the perpendicular; but as, on its emergence from the glass at the point *n*, it deviates from the perpendicular by exactly the same amount, it follows that, after having traversed the glass plate, its direction O*n* is exactly parallel to L*m*; whence we conclude that light is not deviated when it traverses a medium with parallel faces, such as the glass in our windows.

This holds only when the two surfaces are quite parallel, and true planes, such as plate glass; seen through ordinary glass, objects often appear out of shape.

343. **Prisms.**—In optics, a *prism* is any transparent medium comprised between two plane faces inclined to each other. Thus, the facettes of a glass stopper taken in pairs form as many prisms.

Fig. 295 represents the shape and arrangement of prisms for optical experiments. It is a piece of glass cut laterally in three plane faces, and the ends of which are also equal and parallel

triangular faces. The three right lines which form the intersection of two faces of the prism are called the *edges.* The mass of glass thus cut may be turned about an axis parallel to its edges; and it is, moreover, mounted on a stand with a double joint, so that it can be placed in any position whatever.

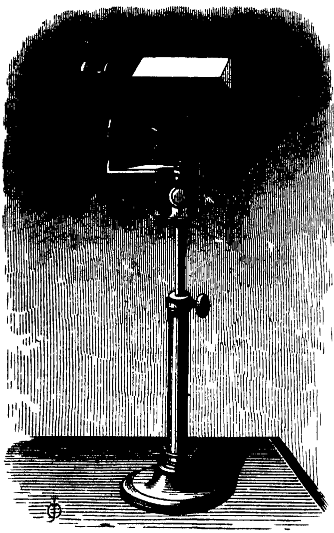


Fig. 295

Prisms produce a remarkable effect upon light which traverses them. First a *deviation*, and second a *decomposition* into various kinds of light. Although these effects are always simultaneous, we shall examine the first by itself: the second will be afterwards investigated under the head of *dispersion.*

344. **Path of rays in a prism.**—To trace the path of a ray of light in passing through a prism, let us suppose this cut by a plane perpendicular to its edges, and let *mno* (fig. 296) be the section thus obtained. If we consider the path of a ray of light L*a* along this section and meeting the prism at *a*, this ray approaches the perpendicular to the surface *mn*, and takes the direction *ab*. But on emerging from the prism it is again broken in the same direction, being deflected away from the perpendicular at the surface *mo*; for it passes into a less refracting medium. It

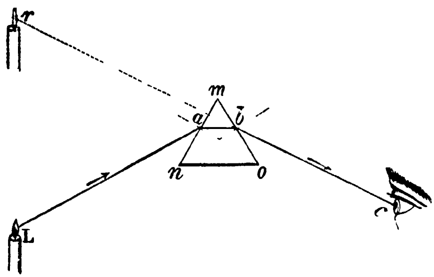


Fig. 296.

forms then a broken line L*abc*; so that the eye which receives the ray, *bc*, which is called the *emergent ray*, sees the object in the

direction *cbr*; that is, raised towards the point *m* (321); which is expressed by saying that an object seen through a prism appears deflected towards the *summit*; that is, towards the edge which separates the faces of incidence and emergence.

The phenomenon is very easily demonstrated by observing any object whatever through a prism, as represented in fig. 297. This is seen to be raised when the summit of the prism is upper-

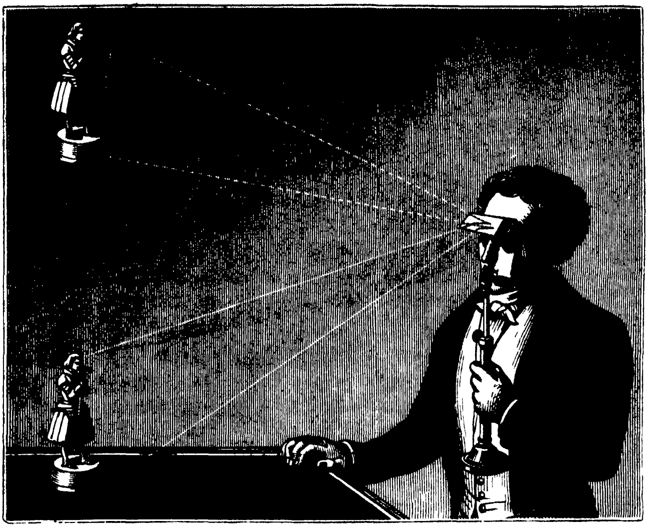


Fig. 297.

most, and lowered when the summit is downward. If the prism is vertical, the image is displaced either to the right or to the left of the observer, according to the position of the summit in either direction.

This property which prisms have, of twice deflecting the light in the same direction, forms the basis of all that has to be said about lenses.

LENSES.

345. **Different kinds of lenses.**—In optics the name *lens* is given to discs of glass bounded by two spherical surfaces, or by a plane and a spherical surface. The true lens, the only

one to which the name is strictly applicable, is that in which both surfaces are bulged or curved, such as represented in a side view in fig. 298, and in front in fig. 299; but this term of lens has been extended to other masses of glass, from the analogy of their action on light.

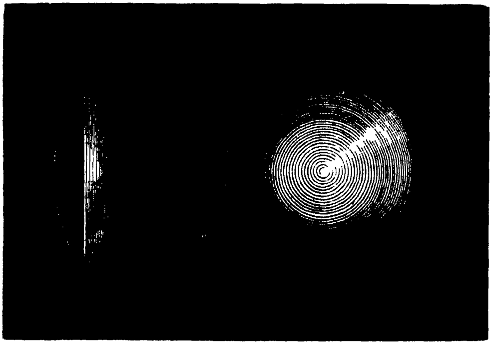


Fig. 298. Fig. 299.

They are usually made either of *crown glass*, which is free from lead, or of *flint glass*, which contains lead, and has greater refractive power than crown glass (337).

The combination of spherical surfaces, either with each other or with plane surfaces, gives rise to six kinds of lenses, sections of

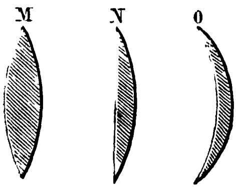


Fig. 300

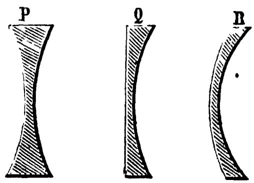


Fig. 301

which are represented in figs. 300, 301; four are formed by two spherical surfaces, and two by a plane and a spherical surface.

M is a *double-convex*, N is a *plano-convex*, O is a *converging concavo-convex*; P is a *double-concave*, Q is a *plano-concave*, and R is a *diverging concavo-convex*. The lens O and the lens R

are also called *meniscus* lenses, from their resemblance to the crescent-shaped moon.

The first three, which are thicker at the centre than at the borders, are *converging*; the others, which are thinner in the centre, are *diverging*. In the first group, the double convex lens, M, only need be considered, and in the second the double concave P, as the properties of these lenses are in principle the same as all those of the corresponding groups.

346. **Principal axis; optical centre; secondary axis.**—Before describing the properties of double convex lenses, we must premise some definitions analogous to those already given for mirrors. A double convex lens is, as shown in fig. 302, the portion common to two spheres which intersect each other. That being understood, the centres C and *c* of these spheres are called the *centres of curvature* of the lens, and the straight line, XY, which passes through these points, is the *principal axis*.

Besides these two centres of curvature, there is a remarkable point in the lenses, called the *optical centre*. This name is given to a point O, on the principal axis, equidistant from the two faces of the lens; at all events, when they have the same curvatures, which is the usual case. Now, it can be shown by geometrical considerations that any ray of light which passes through the optical centre emerges without deflection; that is, it comports itself just as if it traversed a medium with parallel faces (342), while the luminous rays which do not pass through this point are deflected twice in the same direction, as in passing through prisms (344).

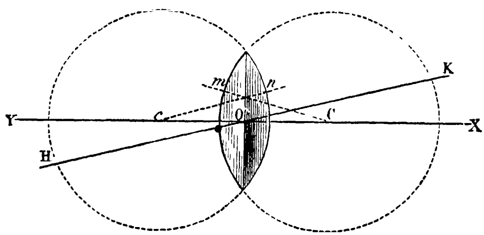


Fig. 302.

Any straight line KH, which passes through the optical centre, without passing through the centres of curvature, is a *secondary axis*. There is only one principal axis, but the number of secondary axes is unlimited. We shall subsequently learn that the principal and the secondary axes play exactly the same part in the formation of images in lenses as they do in concave or convex mirrors.

In order to compare the path of the luminous rays in a lens with that in a prism, the same hypothesis is made as for curved mirrors (328) : that is, the surfaces of these lenses are supposed to be formed of an infinity of small plane surfaces or elements ; the *normal* at any point is then the perpendicular to the plane of the corresponding element : at *m*, for instance, it is the straight line *m*C joining the point *m* to the centre of curvature ; in like manner at *n* the normal is *cn*. This being premised, the properties of lenses are easily deduced from those of prisms (343).

347. **Path of rays in double convex lenses. Foci.**—The rays of light which traverse a lens may be either parallel or divergent ; we will first consider the former case, and suppose further that the rays are parallel to the principal axis, as is shown in fig. 303. Arguing on the above hypothesis, that the curved surface of a lens is an assemblage of small plane facettes, or elements inclined towards each

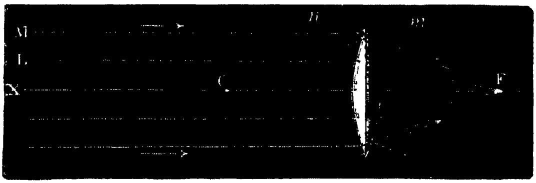


Fig. 303.

other, it will be seen that the ray X, which coincides with the principal axis, traverses the lens perpendicularly to the facettes on entrance and emergence : and that, therefore, it continues to travel in a right line, as traversing in reality a medium with parallel faces. This, however, is not the case with any other ray, L, more or less distant from the principal axis ; for here, the small facettes at the points of incidence and emergence being inclined to each other like the faces of a prism, the ray is twice bent in the same direction, so as to cut the principal axis in a point F. Any other ray, M, is deflected in the same manner, and although more distant from the principal axis, will cut it at F ; which arises from the fact that the two opposite facettes at the points of entrance and emergence, being the more inclined to one another the nearer they are to the edges of the lens, impart to the ray a greater deviation. All rays parallel to the axis behave in the same manner after having traversed the lens, and it can thus be understood how a parallel pencil is transformed into a converging pencil. The point where all the rays

which were parallel to the axis coincide is called, as in the case of mirrors, the *principal focus* or *focal distance*, and we shall represent it by the letter F. It may be formed on either side of the lens, according to the direction in which light falls on the lens.

The focus of a double convex lens is the shorter the greater the curvature of its faces. It depends also on the nature of the material of which the lens is formed; the greater the refractive index (336), the shorter is the focus. Thus, a lens of water, the refractive index of which is 1·336, would have a longer focus than one of glass, whose refractive index is 1·6. A lens of diamond, the refractive index of which is 2·4, or of ruby, again, would have a shorter focus than one of glass.

The position of the principal focus of either a single or double convex lens is fixed and is easy to determine; nothing more is required than to receive on the lens a pencil of parallel rays, a pencil of sun light for instance, and then to hold behind the lens a sheet of white paper. By moving this, a position is found in which the luminous circle formed on the screen is least in size but brightest in lustre: this point is the principal focus.

Where sun light is not available, the principal focus may be determined by ruling a scale on paper, and then holding the lens between it and a movable screen. By varying the position of the lens and screen, a position is found by trial in which the object and its image are of the same size. Measuring then the distance between the image and the object, the focal distance of the lens is one-fourth of this.

348. **Conjugate focus.**—We will now consider the case in which the source of light is at a small distance, but yet farther than the principal focus (fig. 304). The pencil which falls upon the lens being then divergent, it follows that, after having traversed the lens, the rays converge less rapidly than in fig. 303, and that, therefore, they no longer coincide in F, but beyond it, in a point *l*, which is called the conjugate focus of the point L, to express, as in concave mirrors, the correlation of these two points; which is of such a kind that when the luminous object passes from L to *l*, the conjugate focus conversely passes from *l* to L.

The position of the conjugate focus is not fixed; it varies with that of the luminous object: the nearer this is to the lens the more distant is the conjugate focus, as shown by comparing fig. 305 with fig. 304; in fact, the incident rays being more and more diverging, the emergent rays are necessarily so too.

We will now consider the case in which the luminous object, coming continually nearer the lens, ultimately coincides with the principal focus (fig. 306). This being the point where rays parallel to the axis coincide, it follows, conversely, that luminous rays, which start from this point, pursue in the opposite direction the same path as in arriving; that is to say, that they form a pencil parallel to the axis on emerging from the lens, and that in this case no focus can be produced at any distance.

Fig. 304.

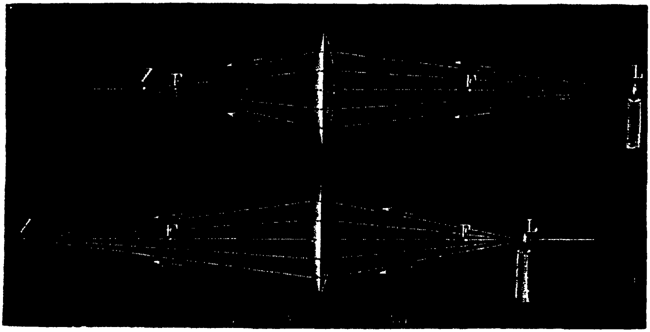


Fig. 305.

349. **Virtual focus.**—We have still to consider another focus the *virtual focus.* Let us suppose that a luminous object, continually coming nearer the lens, ultimately comes between it and the principal focus (fig. 307). The divergence of the incident pencil being then greater than in fig. 306, it follows that the rays after emergence will be more and more spread out than in this figure: they should, therefore, become divergent, as shown in the pencil MN. The eye which receives these rays will suppose that they proceed from the point *l*, where their prolongations coincide. In this point the luminous object will appear; it is then, however, only a virtual focus, just like that in a concave mirror, when the luminous object is placed between the mirror and its principal focus.

350. **Summary of the properties of double convex lenses.**—From what has been said, we may deduce the three following principles as to the properties of double convex lenses.

I. Luminous rays parallel to the axis, after having traversed a double convex lens, coincide in a single point, which is the principal focus (fig. 303) ; and conversely, rays from this focus form, on their emergence from the lens, a pencil parallel to the axis (fig. 306).

II. Luminous rays emitted from a point outside the principal focus converge on emerging from the lens, and coincide in a point called the conjugate focus (fig. 304), which is formed at a greater distance behind the lens, the nearer is the luminous object to the principal focus (fig. 305).

III. Finally, the rays from a point between the lens and the

Fig. 306.

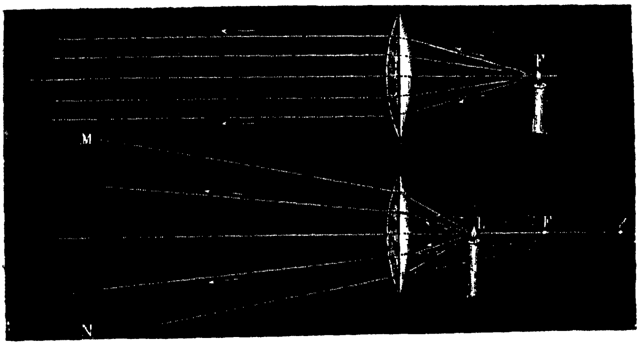


Fig. 307.

principal focus diverge as they emerge, and give rise to a virtual focus on the same side as the object (fig. 307).

A knowledge of these properties of foci is requisite in explaining the formation of images by lenses.

FORMATION OF IMAGES IN LENSES.

351. **Real images in double convex lenses.**—The refraction of light in double convex lenses gives rise to images, which are quite comparable to those seen by reflection in concave mirrors (332), and which, like these, are of two kinds, *real* and *virtual.*

We will first consider the case of the real image. This is formed whenever any object is placed in front of a condensing lens outside its principal focus ; the lens reproduces then, on the other side, a reversed image of the object, which may be caught upon a screen (fig. 308), and is equally remarkable for the fidelity

of the colour and for the accuracy of the outlines; this is the real image. Its formation may be readily understood by reference to what has been said about conjugate foci (348). Yet it must be added that, as all the properties of the principal axis apply also to the secondary axis, it follows that, as a point on the principal axis has always its focus on this axis, so also any point on a secondary axis has its focus on the latter. Hence, in the above figure, all rays from the point A converge at *a* on the secondary axis through this point, and form the conjugate focus of this point, that is to say, its image. In like manner, the image of the point B is formed at *b*, and, as the same is the case for all points of the object, the result is a series of conjugate foci; these in their entirety constitute the image *ab*, which is inverted and smaller;

Fig. 308.

the reversal arises from the crossing of the secondary axes between the object and the image, and its smallness from its being formed nearer the lens than the object is.

Yet the image is not always smaller than the object; it may be larger. For, from the reciprocity between the position of the object and its conjugate focus (348), if, in fig. 308, *ab* were the object, then as the luminous rays pursue the same path, but in the opposite direction, the image would be formed at AB, reversed as before, but larger. A double convex lens may thus give real images, which are either smaller or larger than the object. This may be verified by the following experiment: a double convex lens is placed in a dark room, and in front of it, but some yards beyond the principal focus, a lighted candle. If then there is placed

behind the lens a screen, which can be moved more or less near, a position is found in which there is produced on the screen a very small and inverted image of a candle, as shown in fig. 309. If, on the contrary, the lens be brought nearer he candle, and at the same time the distance of the screen be increased, an inverted image is still obtained, but it is greatly enlarged (fig. 310).

This principle, that *double convex lenses give real and very small images of distant objects*, and, on the contrary, *greatly*

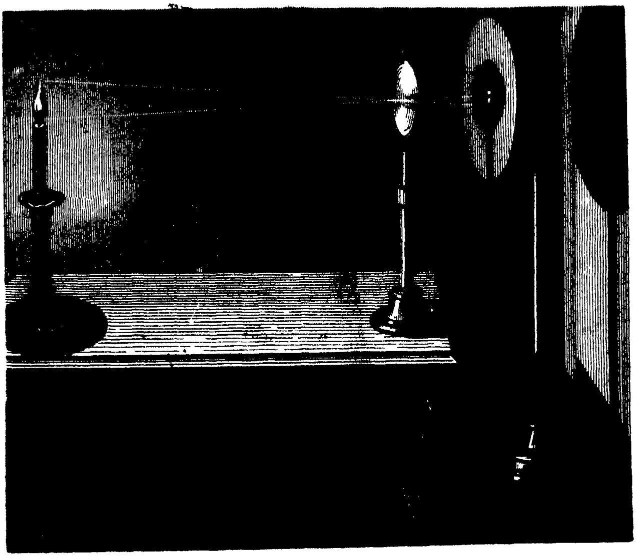


Fig. 309.

magnified images of near objects, will meet with numerous applications in the optical instruments which will be presently described, such as the microscope, the telescope, magic lantern, and phantasmagoria.

352. **Virtual images in double convex lenses.**—Besides the real images we have just considered, double convex lenses give also virtual images, which are produced under the same conditions as the virtual foci; that is, when the object is between the lens and the principal focus. For let an object, *ab* (fig. 311), be placed between

a double convex lens and its principal focus; applying here what was previously said in reference to virtual foci, we know that all rays proceeding from any point, *a*, of the object emerge while diverging, and reach the eye as if they proceeded from the point A, where the prolongation of the same rays coincide, and where there is formed for the eye the virtual image of the point *a*. For the same reason the eye sees at B the image of *b*; hence the image of *ab* appears at AB, but it is virtual; that is to say, it does not really exist, it could not be received on a screen, and is only an optical illusion.

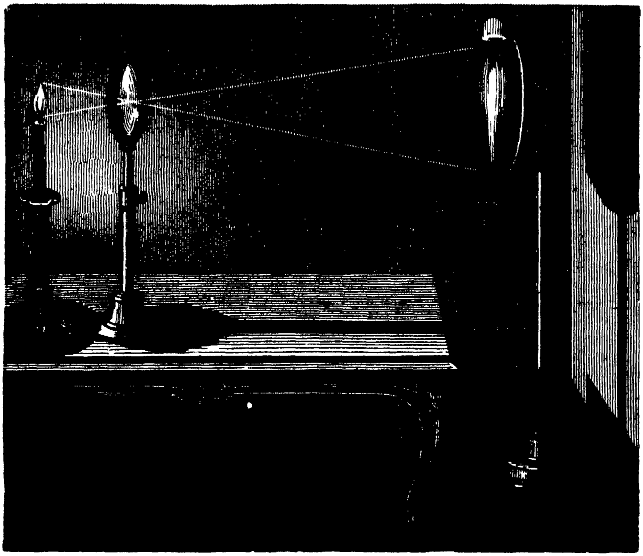
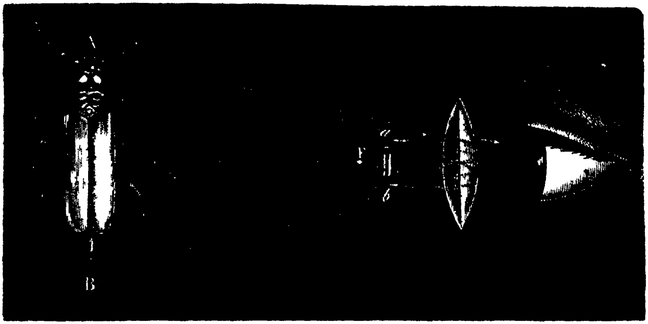


Fig. 310.

It is to be remarked that in opposition to what takes place when the image is real, the virtual image is erect, and in all cases larger than the object; the rectification of the image arises from the fact that the secondary axes do not intersect between the image and the object, but beyond it; the magnification arises from the image being further than the object from the point of intersection of the secondary axes which pass through *a* and *b*.

The term lens is applied to the lenticular glasses used as magni-

fying glasses. Every one is aware that if the print of a book be closely looked at through such a lens it will appear larger; if the lens be gradually removed, a position is reached when the



Fig, 311.

printed characters disappear. This is the case when they are in the principal focus: when it is still further removed the characters reappear; but they are reversed, for they are then beyond the principal focus.

353. **Double concave lenses; foci and images.**—We have seen in speaking about double convex lenses that as the thickness decreases from the centre towards the edges, the small plane facettes, corresponding to the incidence and convergence of the same ray,

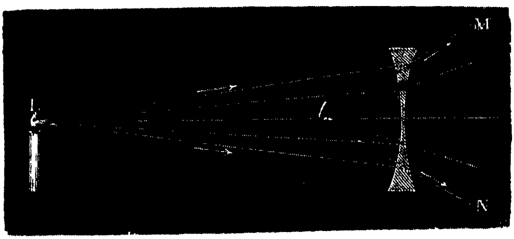


Fig. 312

are more and more inclined from the centre to the periphery. But in double concave lenses, on the contrary, where the thickness increases from the centre to the edge, the small facettes are more

and more apart; and hence the opposite phenomena. For, while double convex lenses cause the rays which traverse them to coincide, by breaking them twice in the same direction, so as to bring them nearer the principal axis, double concave lenses produce the opposite effect, and only increase the divergence of the rays.

This phenomenon may be readily understood by reference to fig. 312, in which it is apparent how the rays are twice broken in the same direction, so as to diverge from the axis, and give rise to the diverging pencil MN. But the eye which receives this pencil is acted upon by it as if the luminous object were at *l*; there is thus produced a virtual focus, the only one possible in double concave lenses.

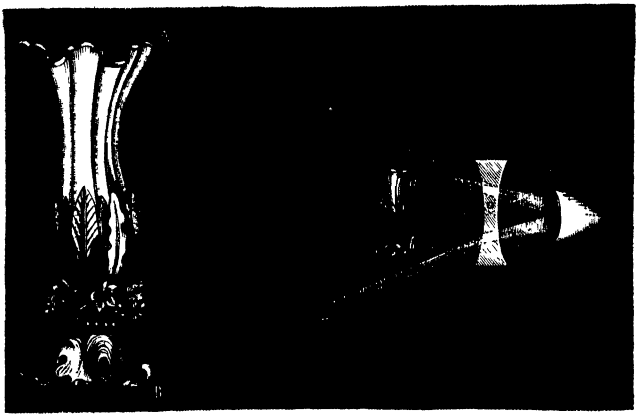


Fig. 313.

As these kinds of lenses have only virtual foci, they can produce none but virtual images; these images are, moreover, always exact and smaller than the object. Thus let AB be an object seen through a double concave lens (fig. 313); the luminous pencil from A is deflected, on passing through the lens, in such a manner as to reach the eye if it were emitted from a point, *a*, on the secondary axis, AO. In like manner, the pencil from the point B reaches the eye as if it started from the point *b*. A virtual image of the object AB, which is smaller and erect, is formed therefore at *ab*, between the secondary axes, AO and BO. This image is

necessarily always smaller than the object, for it is nearer the point O, where the secondary axes intersect.

APPLICATIONS OF LENSES.

354. **Refraction of heat.**—When a pencil of the sun's rays is received on a condensing lens, not merely is light concentrated on its focus, but heat also; for if a piece of an inflammable substance such as tinder, paper, cloth, wood, be placed in the focus, the body soon begins to burn.

This property which condensing lenses have is utilised for producing fire in what are called *burning-glasses*. The focus of a

Fig 314

burning-glass is really only the image of the sun formed by that glass or lens. They may be a source of danger by becoming a source of fire, when a lens is exposed to the solar rays. The same accident may be produced by spherical glass vessels filled with water; for they refract the light and heat like double convex lenses. Thus a vase for holding goldfishes has been known to act as a burning-glass, setting fire to window curtains, near which it had been left in the sunshine. A drop of water, too, on a leaf, concentrates the sun's rays, and frequently marks the leaf.

The concentration of the heat rays of the sun has received a curious application in certain sun dials, when the hour of midday

is marked by the discharge of a small cannon (fig. 314). Above the cannon is a condensing lens, the focus of which exactly corresponds to the *touch-hole* of the cannon the moment the sun passes the meridian of this place. Hence, the cannon being charged and primed beforehand, the lens ignites the powder just at midday, and the explosion announces the time at a distance.

Yet the time thus given is what is called in astronomy *solar time*, or *true time*, in which the length of day varies. Now our watches and clocks, being regulated for *mean time*, that is to say, for an unchangeable day, only agree with the sun four times a year: December 24, April 15, June 15, and September 1. On

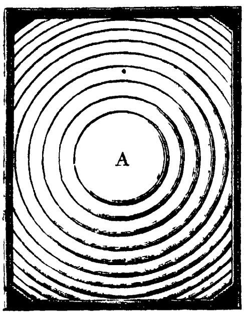


Fig 315

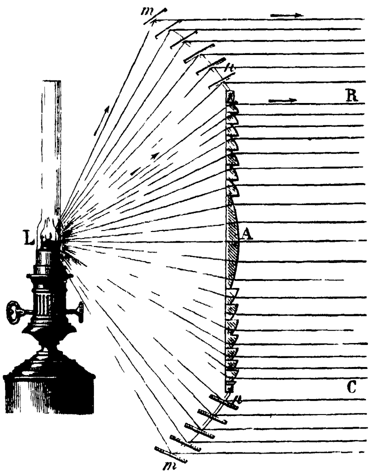


Fig. 316

February 11 a clock giving mean time is 14′ 37″ faster than the sun, and on November 3 it is 16′ 17″ slow. The *equation of time* represents the amount which on all the days of the year must be added to or taken from the time of a clock to obtain the true time. Hence, strictly speaking, it is incorrect to use the ordinary expression, that a good watch or a good clock goes like the sun.

The same principle is applied in the *sunshine recorder*, which consists essentially of a glass sphere on which the sun's rays fall, and their image is received on a strip of millboard stretched in a frame at the proper focal distance. When the sun shines, a mark

is burnt in the millboard, which is not the case when the sun sets or is hidden by a cloud. As the sun moves the position of the spot moves too, and thus we have a series of marks, or, where the sun shines continuously, a line.

Brewster described a lens three feet in diameter, and the rays in passing through it were received on a second lens 13 inches in diameter. The sun's rays were brought to a focus at a distance of 63 inches from the large lens, forming a small circle three-eighths of an inch in diameter. The heat here was so intense as to melt in a few seconds the most refractory metals.

355. **Beacons. Lighthouses.**—These are fires lighted at night on high towers along the shores of the sea, in order to guide mariners in darkness and enable them to keep clear of danger.

Beacon fires were originally wood or coal fires; but these were dull and unsteady. They were afterwards replaced by oil lamps placed in the principal focus of concave reflectors, which sent the reflected light to a great distance, for its rays were parallel.

In 1822 Fresnel made a great improvement in the illumination of *lighthouses*, as they are now called. Abandoning the use of metal reflectors, which soon tarnished under the influence of the sea air, Fresnel substituted large plano-convex lenses, in the focus of which he placed a powerful lamp with four concentric wicks, and equal in illuminating power and quantity of oil consumed to seventeen *Carcel* lamps; this is a standard lamp much used in France and equal to 7·4 candles. But the difficulty of constructing such lenses, which must necessarily be large, and which should at the same time not be thick, so as not to absorb much light, led Fresnel to adopt a special system of lenses, known as *échelon* or *lighthouse lenses.*

Seen in front in fig. 315, and in profile in fig 316, they consist of a plano-convex lens, A, a foot in diameter, round which are arranged eight or ten glass rings, which are also plano-convex, and whose curvature is calculated, so that each has the same focus as the central lens, A. A lamp being placed in the focus of this refracting system, an immense horizontal pencil, RC, is formed which sends the light to a great distance. Above and below these lenses are placed several silvered glass mirrors, *mn*; thus the rays, which would be lost towards the sky and the earth, are utilised and sent in a horizontal direction. By this double combin-

equal intervals of time. These alternations serve to distinguish lighthouses from an accidental fire or a star. By means, too of the number of times the light disappears in a given time, and by the colour of the light, sailors are enabled to distinguish the lighthouses from one another, and hence to know their position.

Of late years the use of the electric light has been substituted for that of oil lamps. A description of the apparatus will be given in a subsequent chapter.

CHAPTER V.

DECOMPOSITION OF LIGHT BY PRISMS.

356. **Solar spectrum.**—In speaking of prisms and lenses, we have only considered the change in direction, which these transparent media produce in luminous rays, and the images which result

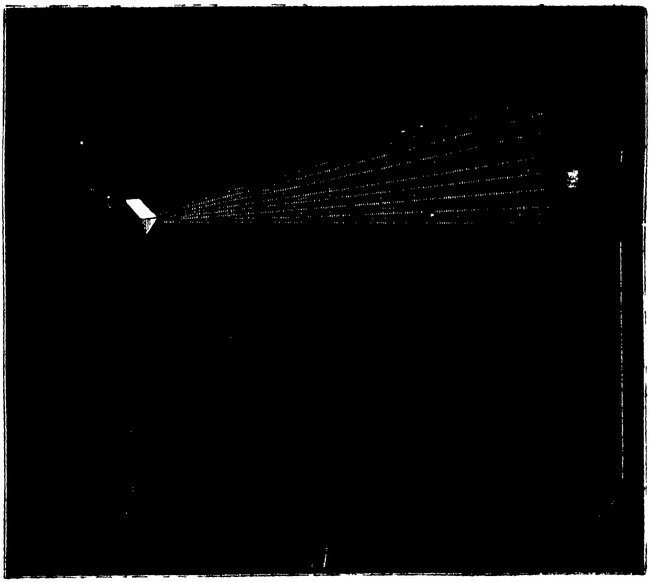


Fig. 310.

therefrom ; but the phenomenon of refraction is by no means so simple as we have hitherto assumed ; when *white* light, or that which reaches us from the sun, passes from one medium into another, *it is decomposed into several kinds of light*, a phenomenon to which the name *dispersion* is given.

In order to show that white light is decomposed by refraction, a pencil of solar light (fig. 319) is allowed to pass through a small aperture in the window shutter of a dark chamber. This pencil tends to form a round and colourless image of the sun on a screen; but if a flint-glass prism arranged horizontally be interposed in its passage, the beam, on emerging from the prism, becomes refracted towards its base, and produces on a distant screen a vertical band, rounded at the ends, coloured in all the tints of the rainbow, which is called the *solar spectrum*. In this spectrum, the production of which forms one of the most brilliant optical experiments, there is in reality an infinity of different tints, which imperceptibly merge into each other; but, with Newton, it is customary to distinguish seven principal colours, as seen in the coloured plate. These are *violet*, *indigo*, *blue*, *green*, *yellow*, *orange*, *red*: they are arranged in this order in the spectrum, the violet being the most refrangible, and the red the least so. They do not all occupy an equal extent in the spectrum, violet having the greatest extent, and orange the least.

From the experiment of the solar spectrum Newton concluded that *white* light—that is, light coming from the sun—is not *homogeneous* (that is, simple), but consists of seven different lights, which, united, give the impression of white, while, when separated, each produces its own colour. He ascribed the separation of these seven lights on their passage through the prism to their different degrees of refrangibility. For if they were all equally refrangible, as they would be equally bent on entering and emerging from the prism, they would traverse it without being separated, and the light would be white on emerging as well as on incidence.

357. **The colours of the spectrum are simple.**—If one of the colours of the spectrum (the yellow, for instance) be isolated by intercepting the others by means of an opaque screen, and if the light thus intercepted be allowed to pass through a second prism, it is deflected, but without decomposition; that is, it only gives rise to a single emergent pencil. As the same phenomenon is observed with the other colours of the spectrum, it is concluded that they are indecomposable by the prism, which is expressed by saying that the seven colours of the spectrum are *simple* or *primitive colours*. The light emitted from luminous bodies is seldom or never simple; on being examined by the prism it will be found to contain more than one colour. In optical researches it is frequently of great importance to procure *homogeneous* or *monochromatic* light.

Common salt in the flame of a Bunsen's lamp gives a yellow of great purity. For red light, ordinary light is transmitted through glass coloured with suboxide of copper, which absorbs nearly all the rays excepting the red.

As regards the cause in virtue of which one part of the spectrum produces on us the sensation of red, another of yellow, another of orange, and so forth, the undulatory theory teaches us that it depends upon the number of vibrations performed by the molecules of the luminiferous ether (309). This number, which is very great, differs with each colour, and increases from red to violet; for the extrême red it is 458 millions of millions in a second, and for violet 727 millions of millions. As the velocity of propagation is the same for all the colours of the spectrum, but each corresponds to an unequal number of vibrations, it follows that the length of these vibrations must vary with different colours. It has been calculated that, in the case of red, the length of the vibration is 620 millionths of a millimetre, and for violet 425 millionths.

358. **Luminous, heating, and chemical effects of the spectrum.**—The various spectral rays differ not only in their colour, but also in their luminous power, in the heat by which they are accompanied, and in the chemical effects to which they give rise. It is found that the middle pencils, the yellow and the green, illuminate the most powerfully. Thus the print of a book placed in the yellow pencil is seen more distinctly than in the red or violet.

The heating action of the spectrum is demonstrated by successively placing a very delicate thermometer, or preferably a linear thermopile, in the various parts of the spectrum. It is observed that the heat attains its greatest intensity in the red, or rather a little beyond it. The existence of these invisible heat rays, which are less refrangible than all other spectral rays (221), was discovered by Sir J. Herschel, from which fact they are called *Herschellian* rays.

Passing from the heating action of light to its chemical action, we find that it tends to destroy most vegetable colours, such as wall papers and dyed stuffs, which rapidly fade if exposed to bright light. Some chemical substances are known which are naturally white, and are blackened by the luminous rays, on which property depends the art of photography: there are gaseous mixtures, also, such as that of hydrogen and chlorine, which suddenly explode when exposed to the sun's rays. These chemical effects are not produced equally in all the parts of the spectrum; the greater chemical action is met with in the violet, and even a little beyond.

Figure 320 represents the distribution of the heating, the luminous and the chemical action of the spectrum; the shaded lines representing the parts of the spectrum which are not visible to the eye, and which, it will be seen, are about equal in length to the luminous parts. The curve I represents the heating effect of the spectrum, from which it will be seen that it is greatest at a little distance outside the visible red; the curve II represents the intensity of the light, which, it will be seen, is greatest near Fraunhofer's line D in the yellow; the greatest chemical, or, as it is sometimes called, *actinic*, action is as follows from the form of the curve III, just about the indigo in the visible part of the spectrum.

359. **Dark lines of the spectrum.**—The colours of the solar spectrum are not perfectly continuous; throughout the whole extent of the spectrum are a great number of very narrow dark lines. They are best observed by admitting a beam of sunlight into a darkened room through a narrow slit. If at a distance of three or four yards we look at this slit through a flint-glass prism, with its

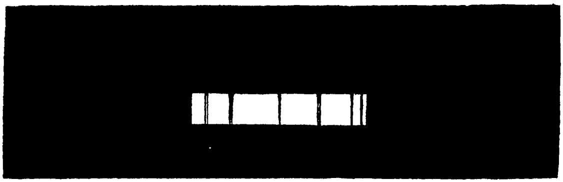
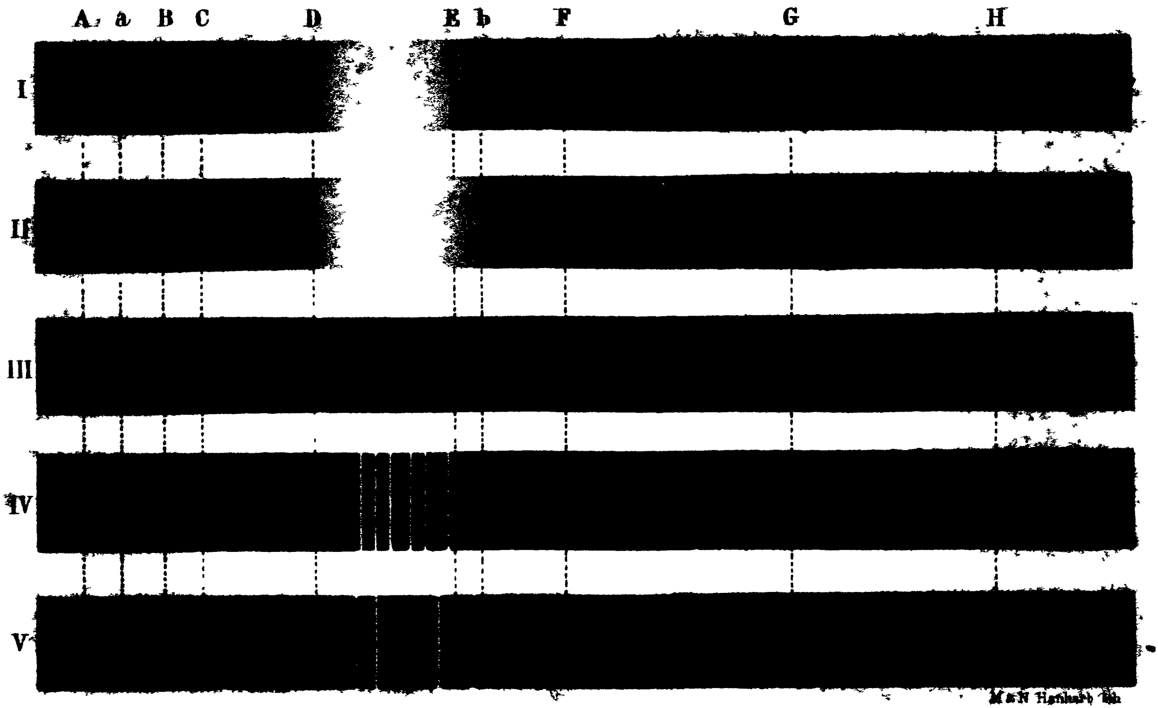


Fig. 320.

edge held parallel to the edge of the slit, we observe a number of very delicate dark lines parallel to the edge of the prism, and at very unequal intervals.

The existence of these dark lines was first observed by Wollaston in 1802; but Fraunhofer, a celebrated optician of Münich, first studied and gave a detailed description of them. He mapped the lines, and denoted the most marked of them by the letters A, *a*, B, C, D, E, *b*, F, G, H; they are therefore generally known as *Fraunhofer's lines.*

The dark line A (see fig. 1 of the coloured plate) is towards the end, and B in the middle of the red; C is in the red but rather nearer the orange ray; D is in the orange ray, E in the yellow, F in the transition from green to blue, G in the indigo, H in the violet. There are certain other noticeable dark lines, such as *a* in the red, and *b* in the green. In the case of the sun's light the posi-


A a B C D E b F G H
I
II
III
IV
V
M & N Hanhart lith

The telescope C has a different function; it contains a micrometric scale photographed on glass, so that it is white on a dark ground. The light from the candle, passing through the scale and the lens in C, falls in parallel rays *on the face* of the prism P, and is *reflected* thence through the object-glass of A, so that the observer, seeing the spectrum and the scale simultaneously, can exactly measure the relative distances of the various spectral lines. M is a metal cap with three apertures, which covers the prism so as to exclude the diffused light.

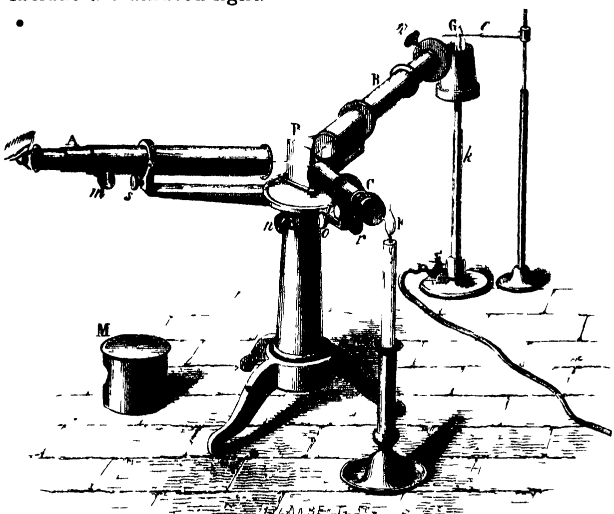


Fig. 321.

Prisms may be combined so that the light is not refracted, but is decomposed and produces a spectrum. Combinations of prisms of this kind are used in what are called *direct vision spectroscopes.* Fig. 322 represents the section of such an instrument in about $\frac{2}{3}$ the natural size. A system of two flint and three crown-glass prisms is placed in a tube which moves in a second one; at the end of this is an aperture *o*, and inside it a slit the width of which can by a special arrangement be regulated by simply turning a ring *r*. A small achromatic lens is introduced at *aa*, the focus of which is at the slit, so that the rays pass parallel through the train of lenses, and the spectrum is viewed at *e*.

Such apparatus are extremely convenient and are indispensable in observing the spectra emitted by bodies which rapidly change their place, such as falling stars. For astronomical purposes they are fitted to telescopes.

Fig. 322.

362. **Experiments with the spectroscope.**—The coloured plate shows certain spectra observed by means of the spectroscope. Fig. I. represents the solar spectrum.

Fig. II. shows the spectrum of potassium. It is *continuous*; that is, it contains all the colours of the solar spectrum; moreover, it is marked by two bright lines, one in the extreme red, corresponding to Fraunhofer's dark line, A; the other in the extreme violet.

Fig. III. shows the spectrum of sodium. This spectrum contains neither red, orange, green, blue, nor violet. It is marked by a very brilliant yellow ray in exactly the same position as Fraunhofer's dark line D. Of all metals sodium is that which possesses the greatest spectral sensibility. In fact, it has been ascertained that one two-hundredth-millionth of a grain of common salt is enough to cause the appearance of the yellow line of sodium. Consequently it is very difficult to avoid the appearance of this line. A very little dust scattered in the apartment is enough to produce it, which shows how abundantly sodium is diffused throughout nature.

Figs. IV. and V. show the spectra of *cæsium* and *rubidium*, metals discovered by Bunsen and Kirchhoff by means of spectral analysis. The former is distinguished by two blue lines, the latter by two very brilliant red lines and by two less intense violet lines. A third metal, *thallium*, has been discovered by the same method by Mr. Crookes in England, and independently by M. Lamy in France. Thallium is characterised by a single green line.

Subsequently to this Richter and Reich have discovered a new metal associated with zinc, and which they called *indium*, from a couple of characteristic lines which it forms in the indigo; and quite recently Boisbaudran has discovered a new metal which he calls *gallium* existing in zinc in very minute quantities.

The extreme delicacy of the spectrum reactions, and the ease with which they are produced, constitute them a most valuable help in qualitative analysis. It is sufficient to place a small portion of the substance under examination on platinum wire, as represented in fig. 321, and compare the spectrum thus obtained either directly with that of another substance, or with the charts in which the positions of the lines produced by the various metals are laid down.

With other metals the production of their spectra is more difficult, especially in the case of some of their compounds. The heat of a Bunsen's burner is insufficient to vaporise the metals, and a more intense temperature must be used. This is effected by taking electric sparks between wires consisting of the metal whose spectrum is required, and the electric sparks are most conveniently obtained by means of Ruhmkorff's coil. Thus all the metals may be brought within the sphere of spectrum observations.

The spectroscope has proved a most powerful instrument of research in astronomical investigation, and has led to most important conclusions respecting many celestial phenomena. An account of them is, however, inconsistent with the scope of this work.

363. **Recomposition of white light.**—Not merely can white light be resolved into lights of various colours, but, by combining the different pencils separated by the prism, white light can be reproduced. This may be effected in various ways.

I. A pencil of solar light is decomposed by a prism, as shown in fig. 323, and the spectrum is received, not on a screen, but on a rather large double convex lens in the focus of which is placed a small cardboard or ground-glass screen. The seven colours of the spectrum coincide in the focus, and there is formed on the screen a perfectly white circular image, which shows that the union of the seven lights of the spectrum reproduces white light.

II. The same result is attained by replacing the double convex lens in the preceding experiment by a concave mirror. The seven coloured pencils being reflected from this mirror, there is formed in the focus the same white image as in that experiment.

III. By means of Newton's disc it may be shown that the combination of the seven colours of the spectrum forms white. This is a cardboard disc of about a foot in diameter (fig. 324) ; the centre and the edges are covered with black paper, while in the space between there are pasted strips of paper of the colours of the spectrum. They proceed from the centre to the circumference, and their relative dimensions and tints are such as to represent five

spectra. When this disc is rapidly rotated, by means of the turning table represented in fig. 324, it appears white, or at all events of a greyish-white: for the colours which cover it cannot be arranged exactly in the same dimensions as those of the spectrum, nor are the tints so pure.

To explain this phenomenon let us observe that the impression produced upon the eye by the sight of a luminous body lasts a

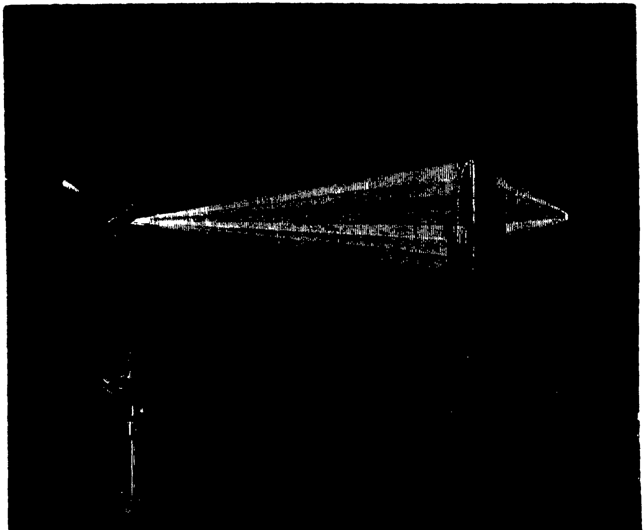


Fig. 323.

certain time after the cause which produced it has ceased. Thus, if a lighted stick be rapidly turned round, a circle of light is produced, which shows that the sensation produced upon the eye lasts after the stick has passed from in front of this organ. A harp string while vibrating as it sounds appears like a thin transparent riband. A sky rocket in its rapid ascent appears like a line of light. Thus,

too, in the above experiment, the disc is turned so rapidly that the action of the seven colours is virtually simultaneous, and the eye is affected as if it received them all together, and the disc therefore appears white.

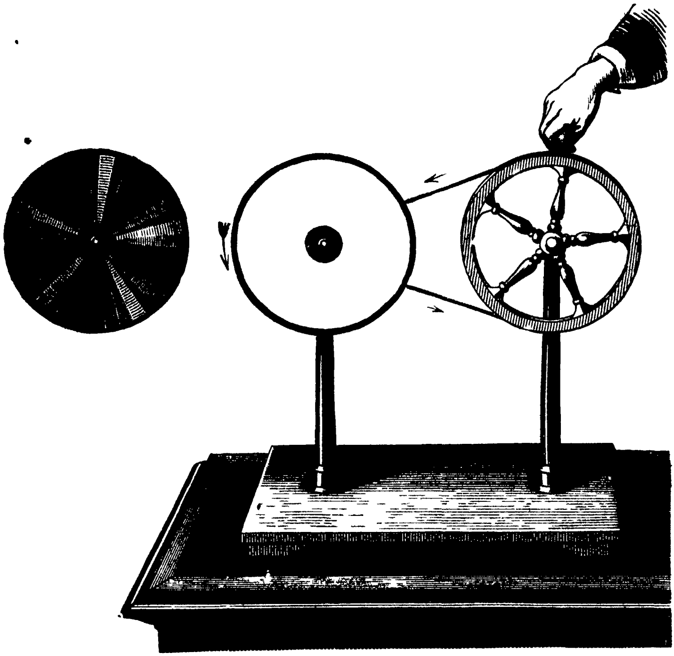


Fig. 324

364. **Zoetrope. Phenakistoscope.**—On the fact that the impression produced on the retina lasts after the cause producing it has ceased to act, depend several interesting experiments ; such are the *zoetrope* or wheel of life ; the *thaumatrope* or magical disc : the *phenakistoscope* or deceiving disc. The latter consists of a disc, near the edge of which are a series of equidistant apertures ; and on corresponding parts of a circle nearer the centre are depicted an object such as a rider on horseback, a bird flying, etc., in various stages of its motion. If, now, the disc be made to rotate rapidly, while the picture side is held in front of a mirror, the eye, on looking

through the apertures, no longer sees the separate stages; on the contrary, they all insensibly merge into each other, and coalesce to form a single impression, which is that of an actually moving body.

If two threads are fixed to the edges of cardboard discs they can be rapidly rotated so that the two sides are alternately seen in rapid succession. If a broad black band is drawn on one side as represented in fig. 325, and a similar one is drawn at right angles to it on the opposite side, on rotating the disc the appearance of a cross is seen. If on one side a bird and on the other a cage are drawn, when the disc is rapidly rotated the bird appears in the cage, etc.

A certain duration of a luminous impression is necessary to produce an effect on the retina; hence it is that we do not see a very rapidly moving object, such as a bullet fired from a gun.

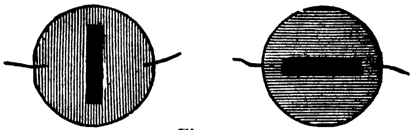


Fig 325.

365. **Newton's theory of the composition of light and the colour of bodies.**—Newton was the first to decompose white light by the prism, and to recompose it. From the various experiments which we have described he concluded that white light was not homogeneous, but formed of seven lights unequally refrangible, which he called *simple* or *primitive* lights.

He was further led to the conclusion that bodies are not of themselves coloured, that is, have no colour of their own, but that they have the property of decomposing the white light, which illuminates them, and of reflecting unequally the various kinds of light of which it is formed. Thus, vermilion is not red of itself, but is endowed with the property of reflecting red light and of absorbing all others, or, at any rate, of only reflecting them in far less proportion. In like manner the leaves of plants are not truly green; they have merely a greater reflecting power for green than for any other colour. In short, bodies are only coloured by the light they reflect. For, let these same green leaves be placed in a spectrum projected in a dark room, if they are in the green band they will appear of a dazzling green, far brighter than their natural colour; but if they are placed in the red they will appear red, and violet if placed in violet. A similar effect is produced if a rose be successively placed in each of the spectral bands, showing that the colours of bodies are not peculiar to them, but depend upon the kind of light which their molecular constitution gives them the power of reflecting.

In speaking, too, of the *green* or the *red pencil*, we do not mean that they are coloured of themselves, but merely that they have the power of producing in us the sensation of green, or of red. The eye judges colours as the ear judges sounds ; both the colours and the sound depend on the number of vibrations.

Bodies which reflect all colours in the spectrum equally well are white, those which reflect none at all are black ; so that black is not really a colour, but the absence of colour.

The varied shades which coloured bodies present result not merely from the fact that they simultaneously reflect various kinds of light, but reflect them to different extents. Thus, a body which reflects yellow and blue light will be green, but a green the shade of which varies with the quantities of yellow and of blue light which the body reflects. If by means of an opaque screen, part or all of certain colours of the spectrum be intercepted, and the others be united by means of a lens, as shown in fig. 326, there is no shade in nature which cannot be reproduced but with a lustre and richness of colour which artificial pigments can never attain.

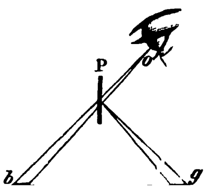


Fig. 326.

The simplest way of mixing coloured light is shown in fig. 326. P is a small flat piece of glass, *b* and *g* are two coloured wafers. The observer looks through the glass plate at *b*, while the coloured light from *g* is reflected from this glass ; if *g* be placed in a proper position, which is found by trials, its image nearly coincides with that of *b*. It then appears as if there was a single wafer at *b* with a colour produced by the mixture of the two real ones. In this experiment the light from *b* which traverses the glass actually unites with that from *g*, which is reflected from it, and the two combined pass on to the retina at *o*.

366. **Colours of transparent bodies.**—We have seen above that opaque bodies owe their colour to the power of decomposing light by reflection— that is, of reflecting certain colours more abundantly than others. It is owing to the decomposition of light that transparent bodies seem to be coloured : though here the decomposition is effected by transmission and not by reflection. If all the rays of the spectrum were equally transmissible by transparent media, they would necessarily be colourless ; that, however, is never quite the case, at all events when the media have a certain thick-

ness : for then they absorb certain colours of the spectrum more than others, and have the tint of the more transmissible colour. Water, for instance, seen by transmission through a great thickness, has a greenish tint, which shows that, of all colours contained in white light, it allows green to pass most easily.

Air, in great thickness, gives a bluish tint to distant objects, which would rather tend to prove that air is more transparent for blue than for any other spectrum colour. It is more probable, however, that this effect is due to the presence of the aqueous vapour in the air.

367. **Complementary colours. After images.**—If in white light, when decomposed by the prism, one or more colours be suppressed, the residue corresponds to one of the tints of the spectrum; and the mixture of the colours taken away produces the impression of another spectral colour. Thus, if in fig. 323 the red rays are cut off from the lens, the light on the focus is no longer white, but greenish blue. In like manner, if the violet, indigo, and blue of the colour disc be suppressed, the rest seems yellow, while the mixture of that which has been taken out is a bluish violet. Hence white can always be compounded of *two* tints; and two tints which together give white are called *complementary colours.* Thus of spectral tints *red* and *greenish yellow* are complementary to each other, so are *orange* and *Prussian blue* ; *yellow* and *indigo blue* ; *greenish yellow* and *violet.*

A distinction must be made between *spectral colours* and *pigment colours.* Thus, a mixture of pigment yellow and pigment blue produces green and not white, as is the case when the blue and yellow of the spectrum are mixed. The reason of this is that in the mixture of pigments we have a case of the substraction of colours, and not of addition. For the pigment blue in the mixture absorbs almost entirely the yellow and red light, and the pigment yellow the blue and violet light, so that only green remains.

Effects of complementary colours are met with in many curious experiments. Thus, let any coloured object, a wafer, for instance, be placed on a black ground, and let it be viewed for some minutes until the sight is fatigued ; if then the eyes be turned to a sheet of white paper, an image will be seen of the same form as the object, but of the complementary colour; that is, that if the wafer is red its image will be green, if it is orange the image will be blue, and so forth. In like manner, if, after looking for some time at the setting sun, the eye be turned to a white wall, an intense green

disc will be seen, which lasts for some minutes, after which the red image appears; a second green image succeeds to it, and so on for a great number of times, until the appearance fades away.

These images, which thus persist sometimes after an object has been looked at, and which have the complementary colours of those of the object, are called the *after images*, or after colours.

There is another kind of after colour: when a coloured object placed on a white ground is attentively looked at for some time, the object is seen to be surrounded by a colour which is complementary to that of the object. This phenomenon, which is known as the *accidental halo*, is easily verified by means of a coloured wafer placed on a sheet of white paper.

When several pieces of cloth of the same colour are successively looked at, it will be seen that the latter ones appear of a bad shade. This arises from the fact that the eye becomes fatigued and the accidental colour of the cloth begins to form, and its own tint loses its brightness. So, too, when designs are printed, or cloth embroidered on a coloured ground, effects may be obtained quite different from those which were desired. Generally, if two adjacent colours are complementary, each will acquire a greater lustre and produce a pleasing impression; but if they are of the same tint they will mutually enfeeble each other. It will thus be seen how numerous are the applications which the phenomenon of accidental images presents in combining colours in pictures wall papers, tapestry, furniture, and even the toilet although in this respect good taste has long beer in advance of the data of science.

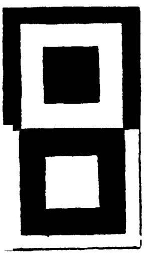


Fig. 327.

368. **Irradiation.**—This is a phenomenon ir virtue of which white objects, or those of a very bright colour, appear larger than they really are when seen on a dark ground. Thus a white square upon a black ground seems larger than an exactly equal black square upon a white ground (fig. 327) With a black body on a bright ground, the con verse is the case. Again, a platinum wire mad red-hot by the passage of an electrical current seems far thicke than it is in reality. Irradiation is held to arise from the fact tha the impression produced on the retina extends beyond the outlin of the image. It bears the same relation to the space occupied by the image that the duration of the impression does to th time during which the image is seen.

The effect of irradiation is very perceptible in the apparent magnitude of stars, which may thus appear much larger than they really are; also in the appearance of the moon when two or three days old, the brightly illuminated crescent seeming to extend beyond the darker portion of the disc, and hold it in its grasp.

Plateau, who investigated this subject, found that irradiation differs very much and in different people, and even in the same person it differs on different days. He also found that irradiation increases with the lustre of the object, and the length of time during which it is viewed. It manifests itself at all distances, diverging lenses increase it, condensing lenses diminish it.

Fig. 328.

369. **Rainbow.**—The *rainbow* is a luminous meteor which appears in the clouds opposite the sun when they are resolved into rain. It contains seven concentric arcs, presenting successively the colours of the solar spectrum. Sometimes only a single bow is perceived, but there are usually two; a lower one, the colours of which are very bright, and an external or *secondary* one, which is much paler, and in which the order of the colours is reversed. In the interior rainbow the red is the hightest colour; in the other rainbow the violet is. It is seldom that three bows are seen; theoretically a greater number may exist, but their colours are so feeble that they are not perceptible.

disc will be seen, which lasts for some minutes, after which the red image appears; a second green image succeeds to it, and so on for a great number of times, until the appearance fades away.

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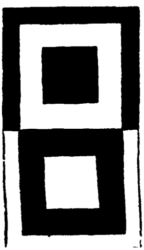


Fig. 327.

368. **Irradiation.**—This is a phenomenon in virtue of which white objects, or those of a very bright colour, appear larger than they really are when seen on a dark ground. Thus a white square upon a black ground seems larger than an exactly equal black square upon a white ground (fig. 327). With a black body on a bright ground, the converse is the case. Again, a platinum wire made red-hot by the passage of an electrical current seems far thicker than it is in reality. Irradiation is held to arise from the fact that the impression produced on the retina extends beyond the outline of the image. It bears the same relation to the space occupied by the image that the duration of the impression does to the time during which the image is seen.

The effect of irradiation is very perceptible in the apparent magnitude of stars, which may thus appear much larger than they really are; also in the appearance of the moon when two or three days old, the brightly illuminated crescent seeming to extend beyond the darker portion of the disc, and hold it in its grasp.

Plateau, who investigated this subject, found that irradiation differs very much and in different people, and even in the same person it differs on different days. He also found that irradiation increases with the lustre of the object, and the length of time during which it is viewed. It manifests itself at all distances, diverging lenses increase it, condensing lenses diminish it.

Fig. 328.

369. **Rainbow.**—The *rainbow* is a luminous meteor which appears in the clouds opposite the sun when they are resolved into rain. It contains seven concentric arcs, presenting successively the colours of the solar spectrum. Sometimes only a single bow is perceived, but there are usually two; a lower one, the colours of which are very bright, and an external or *secondary* one, which is much paler, and in which the order of the colours is reversed. In the interior rainbow the red is the hightest colour; in the other rainbow the violet is. It is seldom that three bows are seen; theoretically a greater number may exist, but their colours are so feeble that they are not perceptible.

The phenomenon of the rainbow is produced by the decomposition of the white light of the sun when it passes into the drops, and by its reflection from their inside face. In fact, the same phenomenon is witnessed in dewdrops and in jets of water; in short, wherever solar light passes into drops of water under a certain angle.

The appearance and the extent of the rainbow depend on the position of the observer, and on the height of the sun above the horizon; hence only some of the rays refracted by the raindrops, and reflected in their concavity to the eye of the spectator, are adapted to produce the phenomenon. Those which do so are called *effective rays*.

To get a general idea of this let us refer to fig. 328, in which two raindrops, *a* and *c*, are represented extremely magnified as compared with the arc of which they form part. The pencil of white light which falls upon *a* is refracted on entrance into the droplet and decomposed, giving rise to seven rays, red, orange, yellow, green, blue, indigo, and violet (356). At the point *a*, on the posterior face of this droplet, a portion of the refracted light escapes, and is dispersed in the atmosphere without giving rise to any particular phenomenon; the light which has not emerged from the droplet is collected at *a*, returns and emerges in being a second time refracted, and reaches the observer's eye as represented in the figure.

A second droplet, *c*, placed below the preceding one, produces just the same effect, yet it does not send the same colour to the spectator. For, as the different colours are unequally refrangible, the coloured rays which emerge from the same raindrop diverge, and therefore are not propagated together, whence it follows that each drop only sends one kind of colour towards the observer. But from the different degree of refrangibility of each ray, the droplets on the outside of the arc send only red rays towards the eye, and those on the inside violet rays. The other colours arise from intermediate droplets.

In short, the rainbow is the circumference of the base of a cone, the apex of which is the observer's eye, and the surface of this cone is formed from the outside to the inside of seven successive envelopes, red, orange, yellow, etc., corresponding to each of the bands of the spectrum. The nearer the sun is to the horizon, the larger is the visible part of the rainbow; but, as the sun rises, the arc diminishes, and entirely disappears when the sun is 42 degrees above the horizon. Hence the rainbow is never seen except in the morning and evening, or, in rare cases, near midnight, when a full moon is low in the south.

CHAPTER VI.

EFFECTS OF COLOUR IN LENSES. ACHROMATISM.

370. **Chromatic aberration.**—In speaking of single lenses we have been silent about a serious defect which they possess, which is, that objects seen through these lenses at a certain distance seem surrounded by an iridescent fringe, which fatigues the sight and greatly injures the precision of the images.

For, as lenses may be compared to a series of prisms with infinitely small faces, and united at their bases, they not only refract

Fig. 329.

light, but also decompose it like a prism. On account of this dispersion, therefore, lenses have really a distinct focus for each separate colour. In condensing lenses, for example, the red rays, which are the least refrangible, form their focus at a point R on the axis of the lens (fig. 329), while the violet rays, which are most refrangible, coincide in the nearer point, V. The foci of the orange, yellow, green, blue, and indigo are between these points. Hence a double convex lens tends to give seven images, differently coloured, of objects seen through it. These images being partly superposed, the seven colours combine in the centre to form white light, but, on the contours, the extreme colours of the spectrum are visible; that is, more especially red and blue.

Hence if a white screen be placed at *mn*, nearer the lens than its focal distance, we shall have a bright circle surrounded by a red

edge ; while if the screen is placed at *rs*, which is farther than the focus, the circle will have a blue edge.

This injurious colouration of the images is called the ***chromatic aberration.***

The inequality in the refraction of the blue and red rays may be demonstrated by closing a small aperture, half with red and half with blue glass (fig. 330); on each half a black arrow is painted, and a lamp is placed behind it. By means of a lens 2 feet focal length an image is formed on a screen at a distance of about 2 metres. If the screen be placed so that a sharp image is obtained of the black object on the blue ground, the outlines of the other are confused. To get a sharp image of the arrow on the red ground the screen must be moved farther away.

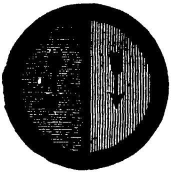


Fig. 330.

371. **Achromatic lenses.**—By observing the phenomenon of the dispersion of colours in prisms of water, of oil of turpentine, and of crown glass, Newton was led to suppose that dispersion was proportional to refraction. He concluded that there could be no refraction without dispersion, and therefore that achromatism was impossible. Almost half a century elapsed before this was found to be incorrect. Hall, an English philosopher, in 1733, was the first to construct achromatic lenses, but he did not publish his discovery. It is to Dollond, an optician in London, that we owe the greatest improvement which has been made in optical instruments. In 1757 he combined two lenses, one a double convex *crown glass* lens, the other a double concave lens of *flint glass* (fig. 331), a kind of glass which contains a good deal of lead, and which has greater dispersive power than crown glass.

Fig. 331.

By suitably choosing the curvatures of these two lenses, they may become unequally dispersive, and as the dispersion is in opposite directions, one of the lenses being convergent, and the other divergent, two effects are produced, which compensate each other as regards colouration, but not as concerns refraction; that is, a ray of white light which has traversed such a lens emerges colourless, but converging, and forming a single focus on the axis.

The lenses thus formed of flint and crown glass give images which are not coloured on the edges ; they have hence been called

achromatic lenses, *achromatism* being the term applied to the phenomenon of the refraction of light without decomposition.

372. **Spherical aberration.**—Chromatic aberration is not the only defect which lenses present: they have another, which is known as *spherical aberration*, and which arises from the fact that, apart from dispersion, the rays which traverse a condensing lens do not exactly coincide in a single focus. Those which traverse the lens near the edges VV′ (fig. 332) are more refracted than those which traverse the central part; hence the former rays converge at F, nearer to the lens than the latter, which meet at G, in consequence of which the images are distorted.

If a screen be held between the light and an ordinary double convex lens which quite covers the lens, but has two concentric

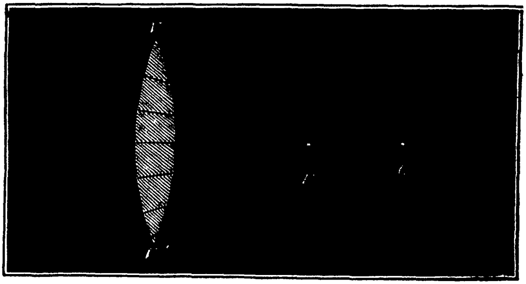


Fig. 332.

series of holes, two images are obtained and may be received on a sheet of paper. By closing one or the other series of holes by a flat paper ring, it can be easily ascertained which image arises from the central and which from the marginal rays. When the paper is at a small distance, the marginal rays produce the image in a point and the central ones in a ring; the former are converged to a point and the latter not. At a somewhat greater distance the marginal rays produce a ring and the central ones a point. It is thus shown that the focus of the marginal rays is nearer the lens than that of the central rays.

Spherical aberration is prejudicial to the sharpness and definition of an image. If a ground-glass screen be placed exactly in the focus of a lens, as in a camera obscura (390), the image of an object will be sharply defined in the centre, but indistinct at the edges; and, *vice versâ*, if the image is sharp at the edges, it will

be indistinct in the centre. This defect is very objectionable, more especially in lenses used for photography.

By suitably choosing the curvatures of the faces, especially when a system of lenses is used, this defect can be greatly diminished. It is also obviated by intercepting the rays which traverse the lens near the edge by *diaphragms* or *stops*, which are opaque screens perforated by circular holes, and which only allow the central rays to pass. The image thereby becomes sharper and more distinct, though the illumination is less.

A combination of lenses by which spherical aberration is got rid of is called an *aplanatic* system of lenses.

CHAPTER VII.

OPTICAL INSTRUMENTS.

373. **Different kinds of optical instruments.**—By the term *optical instrument* is meant any combination of lenses, or of lenses and mirrors. By their means the limits of vision have been enormously increased, and the most favourable influence has been exerted on the progress of science, by opening out new worlds to investigation which would otherwise have remained unknown. Optical instruments may be divided into three classes, according to the ends they are intended to answer—viz.: i. *Microscopes*, which are designed to obtain a magnified image of any object whose real dimensions are too small to admit of its being seen distinctly by the naked eye. ii. *Telescopes*, by which very distant objects, whether celestial or terrestrial, may be observed. iii. *Instruments* for projecting on a screen, a magnified or diminished image of any object, which can thereby be either depicted or be rendered visible to a crowd of spectators: such as the *camera lucida*, the *camera obscura*, *photographic apparatus*, the *magic lantern*, the *solar microscope*, the *photo-eletric microscope*, etc. The two former classes yield virtual images; the last, with the exception of the *camera lucida*, yield real images.

General composition of optical instruments. Of the various instruments enumerated above, those of the first two groups consist essentially of two lenses; one called the *object-glass*, or *objective*, receives the light from the objects, and concentrates it in a focus, where it gives a small image; the other, called the *eyepiece*, or *ocular*, acts as a magnifying glass, is near the eye, and serves to view the image formed by the object-glass. In what are called *reflecting telescopes*, a concave mirror is used instead of an object-glass. Generally speaking, the object-glass and the eyepiece are not formed of a single glass, but of several, in order to obtain a greater magnifying power, and to correct chromatic and spherical aberration (372). These glasses are, moreover, mounted in long metal tubes, blackened on the inside, so as to absorb the oblique rays, which

would otherwise injure the sharpness of the image. These tubes can further be slid in or out, so that the glasses may be brought to the proper distance.

374. **Galileo's telescope.**—Like some other great discoveries, that of the telescope seems to have been due to chance. For it is stated to have been made accidentally by the children of a Dutch spectacle-maker at Middlebourg. Looking at a vane on the top of a church spire through a convex and concave glass, the latter being nearer the eye, they were surprised to see the object magnified, and apparently almost within reach. The father repeated the experiment, and arranged the two glasses in tubes, one of which slid in the other, and thus constructed the telescope.

This telescope bears Galileo's name, for this illustrious astronomer was the first to direct it towards the heavens, and to make astronomical observations. It is stated that he was at Venice when he heard that Zacharia Jansen had offered to Prince Maurice of

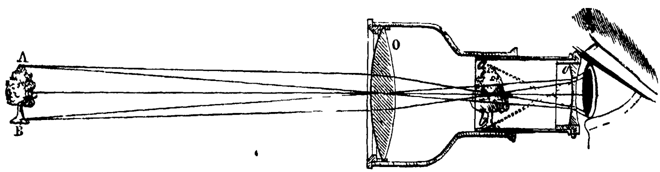


Fig. 333.

Nassau an instrument which brought objects nearer. He quickly started for Padua, where, after meditating on the matter, he made some experiments, and in twenty-four hours rediscovered the telescope.

The telescopes constructed by Galileo were gradually improved from a magnifying power of four up to one of thirty times. By its means Galileo discovered the mountains of the moon, Jupiter's satellites, and the spots on the sun.

Fig. 333 represents the arrangement of the lenses and the path of the rays in Galileo's telescope. The object-glass, O, is a double convex, while the eyepiece, *o*, is a double concave lens. If AB is the object observed, the rays, from any one of its points, A, for instance, tend to form an image of this point beyond the object-glass; but meeting the double concave lens, *o*, these rays appear divergent, and seem to the eye which receives them as if they proceeded from the point *a*; and it is there the image of A appears. In like manner

the image of B is formed at *b*, so that a virtual image, *ab*, is formed which is erect, and very near.

Galileo's telescope is very short and portable. It has the advantage of showing objects in their right position, and further, as it

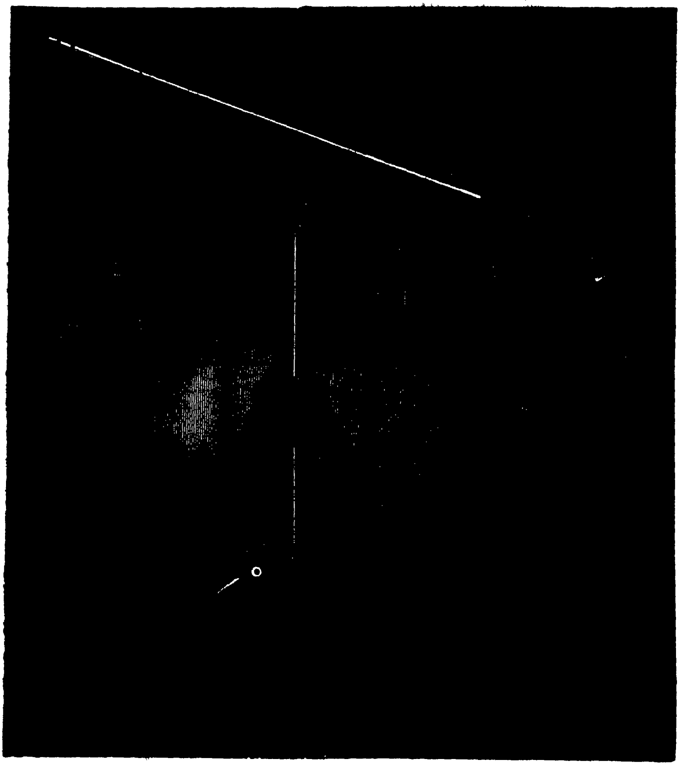


Fig. 334.

has only two lenses, it absorbs very little light; in consequence, however, of the divergence of the emergent rays, it has only a small field of view, and in using it the eye must be placed very near the eyepiece. The eyepiece can be moved to or from the object-glass, so that the image is always formed at the distance of distinct

vision. *Opera-glasses* are constructed on this principle. They are usually double, so as to produce an image in each eye, by which greater brightness is attained.

375. **Astronomical telescope.**—In observing the stars a telescope with two condensing lenses is used, in order to obtain a greater field of view. Its invention is due to Kepler, and it is known as the *astronomical telescope.* It gives reversed images of objects, but this is not prejudicial in observing the stars.

Fig. 334 represents an astronomical telescope with a cast-iron support, and mounted with a hinge motion on a column of the same metal; so that, not only can any degree of inclination be imparted to it, but it can be directed to any part of the horizon. By means of a handle and two toothed wheels the telescope can be raised or lowered at pleasure. On the side of the telescope is a smaller one called the *finder*; for, as it magnifies less than the large one, it embraces a greater extent of sky, and therefore is more suited for finding any given star, which is then observed more minutely with the large glass.

Fig. 335 represents the arrangement of the lenses, and the path of the rays in an astronomical telescope. It consists of two double

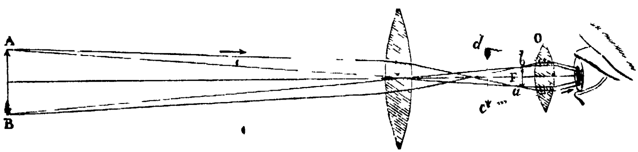


Fig. 335.

convex lenses; the object-glass, which is of large diameter, and but slightly convergent, gives at *ab* a reversed and very small image of the star towards which the telescope is directed. This image is looked at through the eyeglass, O, which acts here as a magnifying glass, and which, for that purpose, is placed so that the image, *ab*, is formed between this glass and the principal focus, F. Thus the observer sees a reversed and greatly enlarged image of the star at *cd*.

As in all telescopes, the *eyetube*, that is, the tube in which is the eyepiece, slides in the other, so that it can be brought nearer or further from the image, *ab*, which can thus be seen at the distance of distinct vision. In powerful telescopes the eye glass is not simple as in the above case, but consists of a number of glasses, the object

of which is not only to increase the magnifying power, but also to correct spherical and chromatic aberration. There is considerable loss of light, however, when it is necessary thus to multiply the lenses.

The magnifying power of a telescope is greater the greater the diameter of the object-glass, and the less its convexity ; and the more convex, on the contrary, is the eyepiece. The general rule is to *divide the focal distance of the object-glass by that of the eye-glass, and the quotient is the magnifying power of the telescope.* The greatest obstacle met with in the construction of these telescopes is the difficulty of manufacturing large object-glasses.

When the telescope is used to make an accurate observation of the stars—for example, their zenith distance, or their passage over the meridian—a *cross-wire* is added. This consists of two very fine metallic wires or spider threads stretched across a circular aperture in a small metal plate. The wires ought to be placed in the position where the inverted image is produced by the object-glass, and the point where the wires cross ought to be on the optical axis of the telescope, which thus becomes the *line of sight* or *collimation.*

It is very difficult to procure large masses of flint glass free from defects. This is one reason for the costliness of large telescope lenses.

376. **Terrestrial telescope.**—The *terrestrial telescope* differs from the astronomical telescope in producing images in their right positions. This is effected by means of two condensing lenses,

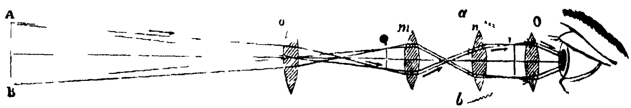


Fig. 336.

which are interposed between the object-glass and the eyepiece, as seen in fig. 336. The object-glass forming then, at I, a reversed image of the object, AB, the two glasses *m* and *n* impart such a direction to the rays traversing them, that, after having crossed between the two glasses, the rays reproduce an erect image at *i*. The eyepiece acts then just as in the astronomical telescope, giving a very near, erect, and magnified image *ab*.

The terrestrial telescope is sometimes mounted on a stand, and sometimes held in the hand. Its uses are too well known to need any description.

In order to determine by direct experiment the magnifying

power of a telescope when this is not great, a divided scale at a distance, or the slates or tiles of a house, or a number of courses of bricks, may be viewed through the telescope with one eye and directly with the other. It is thus observed how many unmagnified divisions correspond to a single magnified one. Thus, if two seen through the telescope appear like seven, the magnifying power is $3\frac{1}{2}$.

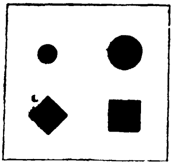


Fig. 337.

The excellence of a telescope depends also on the sharpness of the images. To test these various circular and angular figures are painted in black on a white ground, as shown in fig. 337, in about $\frac{1}{10}$ the full size. When these are looked at through the telescope at a distance of 80 or 100 paces, they should appear sharply defined, perfectly black, without distortion, and without coloured edges, showing that the telescope is achromatic. Reading a book in ordinary type adjusted at a distance is also an excellent means of testing and comparing telescopes.

377. **Reflecting telescopes.**—The telescopes previously described are *refracting* or *dioptric* telescopes. It is, however, only in recent times that it has been possible to construct achromatic lenses of large size; before this a concave metallic mirror or

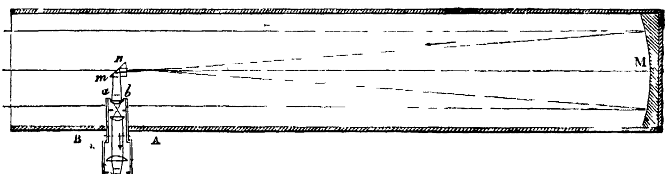


Fig. 338.

speculum was used instead of the object-glass. Telescopes of this kind are called *reflecting* or *catoptric telescopes*. The principal forms are those devised by Gregory, Newton, Herschel, and Cassegrain.

Of these we shall describe the Newtonian telescope, which, after long disuse, has been restored to favour, in great measure owing to the improvements made in the construction of the concave mirror used in it.

Fig. 338 represents the section of a Newtonian telescope as modified by Foucault, and fig. 339 a perspective view. The prin-

cipal piece of the telescope is a concave mirror M, placed at the end of a long wooden tube. These mirrors were formerly of metal, and the difficulty of working such mirrors, so as to give

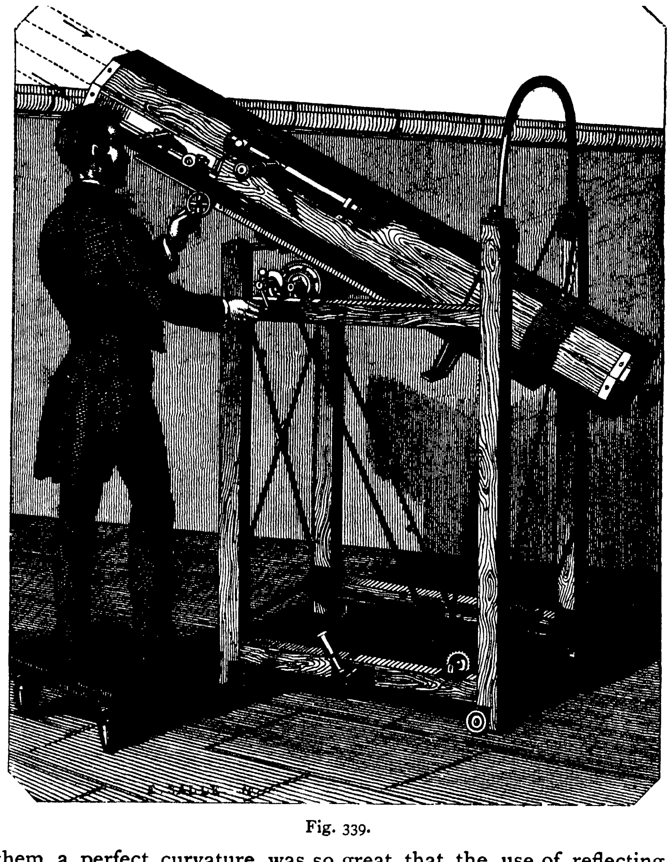


Fig. 339.

them a perfect curvature, was so great that the use of reflecting telescopes was virtually abandoned.

Foucault having discovered a method of silvering glass without injuring its polish, and as glass is more easily worked than metal mirrors, reflectors for telescopes are now made of polished glass,

silvered on the concave surface itself; the rays of light which come from the star observed are there reflected, and tend to form at the other end of the tube a real and very small image of the star; but these rays fall upon a small rectangular prism *mn*, into which they pass without being refracted, and form with the large face, *mn*, such an angle of incidence that they are *totally* reflected out instead of being refracted (340). The image is then formed at *ab* in front of a horizontal tube, in which are a series of magnifying glasses, which act as ocular, and give of the image *ab* a very amplified virtual image AB.

Fig. 339 shows how the instrument is worked. The right hand of the observer holds a handle which transmits the motion to an endless chain, and this to two other chains, which pass round pulleys, and enable the tube to be more or less inclined. With the left hand the same observer turns a small wheel, fixed to a screw which enables him to move slowly the front part of the apparatus in a lateral direction, so that he can follow the star in its motion. A little lower than the eyepiece and above the small wheel is a milled head, which works a small rack and pinion motion. This is fixed to a movable piece, which, at the same time, supports the prism, *mn*, and the eyepiece (fig. 338). By turning this milled head in either direction, the prism and the eyepiece may be adjusted until the image AB is formed at the distance of distinct vision of the observer.

On the side of the tube is a small telescope, quite similar to the large one, but of far less magnifying power. This is the *finder*. From its small magnifying power, not more than ten, it embraces a far greater extent of the sky, and is therefore more favourable for finding the desired star.

378. **Herschel's telescope.**—Sir W. Herschel's telescope, which until lately was the largest instrument of modern times, was constructed on a method differing from those described. The mirror was so inclined that the image of the star was formed on the side of the telescope near the eyepiece (fig. 340); hence it is termed the *front view* telescope. As the rays in this telescope only under-

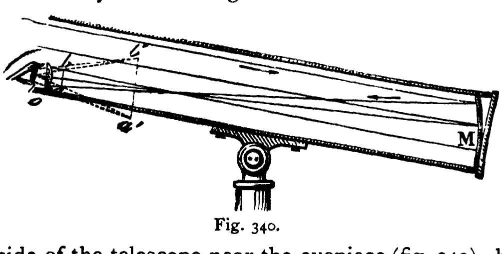


Fig. 340.

go a single reflection, the loss of light is less than in either of the preceding cases, and the image is therefore brighter. The magnifying power is the quotient of the principal focal distance of the mirror by the focal distance of the eyepiece.

Herschel's great telescope was constructed in 1789; it was 40 feet in length; the great mirror was 50 inches in diameter. The quantity of light obtained by this instrument was so great as to enable its inventor to use magnifying powers far higher than anything which had hitherto been attempted.

Herschel's telescope has been exceeded by one constructed by the late Earl of Rosse. This magnificent instrument has a focal length of 53 feet; the diameter of the mirror is 6 feet; and it weighs 8,400 pounds. It is at present used as a Newtonian telescope, but it can also be arranged as a front view telescope.

MAGNIFYING INSTRUMENTS.

379. **Simple microscope.**—*Microscopes* are instruments which, giving very magnified images, enable us to observe objects which are too small to be seen with the naked eye. Two kinds are distinguished, the simple and the compound microscope.

The first of these is essentially a small highly convergent lens, which is used as a magnifying glass, as seen in fig. 341. The object observed is then placed between the lens and its principal focus, and the magnifying power is greater the more condensing is the lens. When it is rather large it is mounted in horn or in ivory, and is then known as a reading lens or reading glass. It is frequently used to assist the sight of the aged, or to facilitate certain kinds of work, which, as in watchmaking and engraving, require great accuracy. No great magnification is attainable with a single microscope, and, in order to observe very small

Fig. 341.

E

objects, the *compound microscope* is used, which is so called since it is made up of several lenses.

If a drop of Canada balsam be allowed to fall on a glass plate, it will assume the form of a plane convex lens, and by holding the

Fig. 342.

plate horizontally with the drop downwards it gradually becomes more convex. It soon becomes hardened, and if protected from dust is tolerably durable. Such an arrangement forms a magnifying lens.

380. **Compound microscope.**—Fig. 342 represents the mode of using a compound microscope, and fig. 343 the path of the luminous rays in the interior of the apparatus. The object, which is always very small, is placed at *a*, between two glass plates, on a support called the *stage*. OA*o* is a brass tube in which are two condensing lenses, the *object-glass o*, at the bottom, and the *eyepiece* O, at the top. The object, *a*, being placed very little beyond the principal focus of the eyepiece, we know that a real, erect, and greatly magnified image will be formed at *bc* (350). But, as the eyepiece, O, is at such a distance that the image, *bc*, is between this glass and its principal focus, F, it follows that the eyepiece acts as a lens for an eye looking through it (351), and gives at BC a virtual and amplified image of the first image *bc*. It may thus be said that the compound microscope is nothing more than a simple microscope applied not to the object, but to its image already magnified by the first lens.

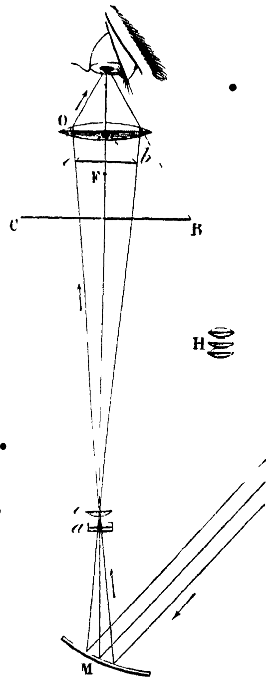


Fig. 343.

The magnification depends more especially on the object-glass. In order to increase its power it consists of two or three small lenses superposed, as seen in H, on the right of the drawing (fig. 343). To the eyepiece a second glass is used, the object of which is less to obtain increased magnification than to render the images more defined by diminishing, as in telescopes, chromatic and spherical aberration. All the glasses are, moreover, achromatic. The magnifying power in compound microscopes has been carried to 1,800 times, and even more, but then what is gained in magnification is lost in definiteness. A good magnification does not exceed 600 in length and breadth ; this is called a magnification of two diameters, which amounts to a superficial enlargement of 360,000 times.

From the great magnification of the image the object must be powerfully illuminated. For this purpose, when it is sufficiently transparent, it is illuminated from below by a concave mirror, M, which concentrates upon it a large quantity of light, as shown in fig. 343. If the object is opaque, it is illuminated above by a condensing lens, L (fig. 342), the focus of which is formed upon the object itself.

381. **Origin and use of the microscope.**—The invention of the microscope does not extend further back than to the last quarter of the seventeenth century, which is surprising, for it had long been known that a drop of water placed in a small hole in a thin opaque plate magnified objects seen through it. From the commencement of the first century A.D., the philosopher Seneca announced that writing appeared larger under a glass globe containing water. In the thirteenth century, *spectacles* were first used—that is, magnifying glasses—to assist the sight of the aged. They are said to have been discovered by Salvino degli Armati, a Florentine nobleman. The inventor of the microscope is not known: it has, probably, only acquired its present form after numerous successive improvements.

The microscope has been the origin of discoveries in the vegetable and animal kingdom, as curious and important as they are varied. Botanists owe to it their most beautiful discoveries concerning the structure of the cellular tissue in plants, the circulation of the sap, the function of leaves in the respiration of vegetables. In entomology it has enabled us to discover a crowd of small animals which would otherwise have remained unknown from their extreme minuteness. Thus there have been observed, in vinegar and in sour paste, thousands of small organisms called *vibrions*; in stagnant water myriads of animalcules, as remarkable for their curious forms as for their beautiful colours, their instincts, their warlike or sociable habit. Mould presents the appearance of small mushrooms with the most brilliant colours. In short, any object seen through the microscope becomes an object of astonishment and admiration; thus, for instance, a hair, a piece of silk thread, the eye or wing of a fly, a bee's sting, a spider's claw, a cat's or mouse's hair, the down of fruit, the scales of a butterfly's wing or of fish, starch grains, spider-web, etc., everywhere we recognise the infinite variety of Nature's works.

The simple microscope may also be advantageously used to recognise fraudulent mixtures in cloths of various kinds, by giving

a means of ascertaining whether they contain wool or silk, linen or cotton. By the watchmaker it is used to inspect the minute mechanisms with which he has to deal.

The excellence of a microscope depends not so much on the mere magnifying power as on the sharpness, or what is called the *definition*, of the images. They are tested by means of what are called *test objects*, such as particular specimens of a butterfly's wings, or scales of certain diatoms ; or by means of fine lines drawn on glass. Such lines have been drawn of which there are no less than 20,000 in an inch.

CHAPTER VIII.

OPTICAL RECREATIONS.

382. **Magic Lantern.**—In the instruments that still remain to be described, the aim is to project on a screen reduced or enlarged

Fig. 344

images of an object, so as to exhibit them to a number of spectators, or to utilise them for drawing.

The oldest and most simple of these apparatus is the *magic lantern*, which was invented by Father Kircher, a German Jesuit, about two hundred years ago, and is used to project a magnified image of small objects painted on glass on a white screen in a

dark room (fig. 344). It consists of a box of sheet metal in which there is a lamp placed in the focus of a concave mirror, M (fig. 345). The reflected rays fall upon a condensing lens, L, which concentrates them on the figure painted on a glass plate or *slide*, *ab*. There is a system of two lenses, *m*, acting as a single one of great magnifying power, at a distance from *ab* of rather more than its focal distance. At this distance the system of two lenses acts as in the experiment (fig. 344); that is, a real and very much magnified image of the figure on the slide is produced on the screen. The image is made erect by placing in the lantern the slide painted in such a manner that the design is reversed. The image, AB, is formed at so much the greater distance, and is so much the more amplified, the nearer the slide, *ab*, is to the principal focus of the

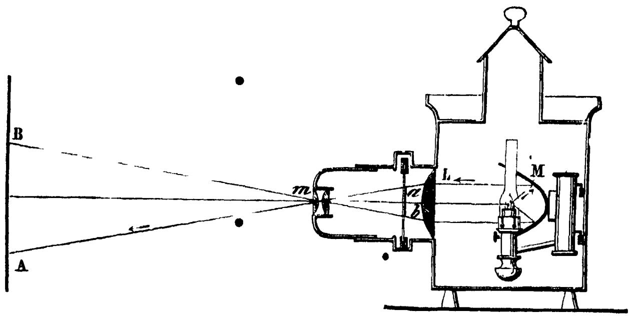


Fig. 345.

system of lenses, *m*, and the greater the magnification of this system.

383. **Phantasmagoria.**—This is only a modification of the magic lantern, and dates from the end of the eighteenth century: its name is derived from two Greek words, which signify *assemblage of phantoms*, for it was originally used to produce fright, by making spectres appear in darkness.

The internal arrangement of the phantasmagoria is just the same as in the magic lantern, the difference being that in the magic lantern the image projected on the screen is always of the same size, while, in the case of the phantasmagoria, the size may be varied at pleasure. To understand how this is effected, let us refer to fig. 345, which represents the arrangement of the glasses in the magic lantern. The lenses, *m*, which are used to project the images on the

screen, being always at the same distance from the painted slide *ab*, the image, AB, is always at the same distance, and is always therefore of the same size. Now if one of the lenses, *m*, be brought nearer the slide, *ab*, it follows from the properties of lenses (347) that the image will be formed at a greater distance, and will be larger. Hence the effect sought requires two movements; one which brings the system of lenses, *m*, nearer the painted slide, to amplify the image; the other, which makes the whole apparatus recede, so that the image, while being moved away, is always formed upon the same screen as at first.

To obtain this double effect, the whole apparatus is mounted upon four small wooden wheels covered with cloth, so that they roll

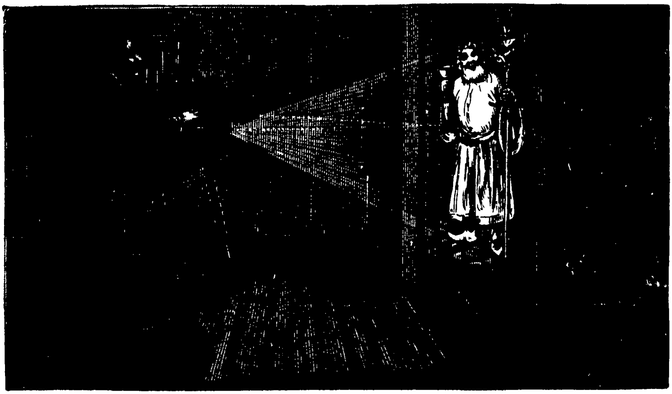


Fig. 346.

noiselessly on the floor. Figure 346 represents a phantasmagoria thus arranged, with the difference that in the figure it is double; that is, consists of two apparatus united. We shall presently see the reason for this double use (384) and for the moment we shall only consider one of the parts. The front of the box is provided with a conical brass tube; in this tube is the projection lens, which is not fixed, but may be advanced or receded by means of a milled head and screw, which the experimenter turns with the hand.

A large white sheet is stretched in front of the apparatus, and the spectators are on the other side of the sheet. The whole being in complete darkness, the experimenter is careful first of all to keep

the projection lens away from the slide, on which are painted the objects he desires to show. Thus there is at first formed on the sheet a very small image of the object. Then, with one hand, the experimenter brings the lens near the slide, while with the other he draws towards himself the apparatus, and away from the cloth. The image projected on the latter gradually increases, and ultimately becomes very large. The spectators, who see the image very distinctly through the cloth, fall into the illusion that its increase in size is due to its coming nearer them. Some authors have supposed that use was made of the phantasmagoria in remote antiquity, and, by means of apparatus of this kind, those initiated into the mysteries of Isis and Ceres were terrified, and the infernal deities evoked were made to appear. Yet there is no evidence indicating that lenses were then known. Concave mirrors, however, would be sufficient for producing effects analogous to those of the phantasmagoria.

384. **Polyorama, or dissolving views.**—The *polyorama* is an application of the phantasmagoria. It is a double lantern as represented in fig. 346, and the two systems of lenses converge towards the same point of the cloth which receives the image. Two pictures on glass are used representing the same view under different conditions; for example, Mount Vesuvius seen at daytime, calm, and with a slight cloud of smoke rising from it; the other when seen at night, vomiting forth flames and torrents of fiery lava. Having arranged these glasses, each in one of the lanterns, and the lenses being so arranged as to project the magnified images on exactly the same part of the cloth, the diaphragm of the one containing the picture representing the effect of day is opened, the other remaining closed. Then when the image has for some time been exposed to the view of the spectators, a mechanism is worked, which gradually closes the one which has been exposed, and opens the other. It follows that, in successively passing through all the shades of light, the image which produces the effect of day disappears, while it is gradually replaced by the effect of night represented on the other. In like manner, too, the effect of the moon rising may be made to succeed to sunset; to a calm and transparent sea, a tempest; to a smiling landscape, a snow effect; and so forth. Hence the name *polyorama*, from two Greek words, which signify several views.

385. **Photo-electrical microscope.**—This apparatus is based on the same principles as the magic lantern and the phantasmagoria.

But, as in these apparatus, the subjects painted on glass are of some size, no great enlargement is required, and therefore the illumination need not be very intense. Whereas objects, the images of which are reproduced by the photo-electrical microscope, being very small, should be considerably magnified, and the light must therefore be very powerful, or else the image will be confused and indistinct. Hence

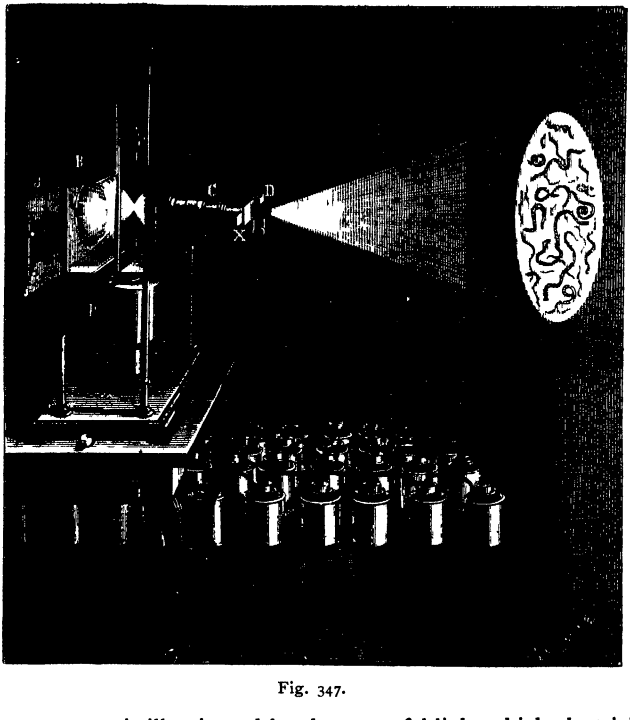


Fig. 347.

the apparatus is illuminated by the powerful light which electricity yields.

Figure 347 represents the use of the photo-electric microscope. On the floor is a series of vessels which serve for the disengagement of electricity, and which we shall afterwards describe as the voltaic battery (469). From these vessels the electricity passes by two stout copper wires to two rods of charcoal contained in the box

B. Thus charged with electricity, these carbons become heated to incandescence, and emit an extremely bright light. A reflector, I, sends the rays of light in the direction of the tube, C, where they meet two condensing lenses, which concentrate them on the very small object which is to be magnified, and which is arranged between two glass plates, X. The rays pass from thence into a tube, D, where there is a system of condensing lenses intended to produce the same effect of projection as the lenses, *m*, in the magic lantern (fig. 344); that is, it is a system of lenses which produces on a white screen at a distance an extremely magnified image of the small object placed between the glass plates. The tube, D, is movable, and may be approached to or receded from the object, so as to vary the magnification.

It should be stated here that the use of the battery producing the electric light has now been superseded by magneto-electric machines, which are more convenient and very considerably cheaper and more powerful.

In the adjacent figure, the image projected on the screen is that of the infusoria which are found in paste when it has fermented. A small quantity is mixed with water, and a few drops put in a small glass box with parallel faces, which is placed at X. A multitude of these animalcules are seen on the screen, ten or twelve inches in length, which move about in a confused mass, and soon die in consequence of the heat which is concentrated along with the light in the focus of the lenses.

386. **Experiments with the photo-electric microscope** are among the most interesting in the whole range of physics. By its means, objects of extreme minuteness may be exhibited, greatly magnified, to a large number of spectators. A hair, for example, looks like a broomstick: a flea like a sheep; the itch-tick, an animalcule found in itch pustules, and by which this disease is propagated, appears like a man's head; the same is the case with the animalcules found in decayed cheese, although these cannot be seen by the naked eye. One of the most remarkable experiments is that showing the circulation of the blood. This is made by placing between two glass plates the tail of a living tadpole, that is to say, the young of a frog before its upper and lower limbs are developed. There is then observed on the screen a kind of illuminated map, all the rivers in which appear to flow very rapidly; this is the blood which circulates in the veins. A very beautiful experiment is the crystallisation of salts, and especially of sal ammoniac. This salt

is dissolved in water, and a drop of the solution is spread on a glass plate, which is placed in the apparatus. As the heat makes the water evaporate, a vegetation quickly forms, which is surprising from the promptitude with which the crystalline molecules group themselves together to produce magnificent ramifications like fern leaves.

The apparatus we have described is sometimes modified, so as to be illuminated by sunlight, and it is then called the *solar microscope.* It may also be illuminated by the intense light produced by allowing the oxyhydrogen flame to impinge upon a piece of lime. It is then called the *oxyhydrogen microscope.*

Fig 348

387. **Camera obscura.**—A Neapolitan physician, Jean Baptiste Porta, first observed in 1680 that if a very small hole be perforated in the shutter of a *dark room*, one that is quite deprived of light, all objects which can reach the hole depict themselves on the opposite screen, and of so much the smaller dimensions the nearer this screen is to the aperture.

Porta also found that by fixing a double convex lens in the aperture, and placing a white screen in the focus, the image was much brighter and more definite. In both cases the images are inverted. Fig. 348 shows how images formed in the camera obscura

are reversed upon the screen It is due to the rays crossing on entering the aperture. It follows, in fact, that rays from the higher parts of the object proceeding in a straight line meet the lower part of the screen, while the reverse is the case with rays from the lower part The colouration of the image is readily understood by observing that the reflected rays are of the same colour as the reflecting body, that is, that a red body reflects red rays, a yellow body yellow rays, and so on Each portion of the image is formed by the coincidence of rays of the same colour as the corresponding part of the object it represents

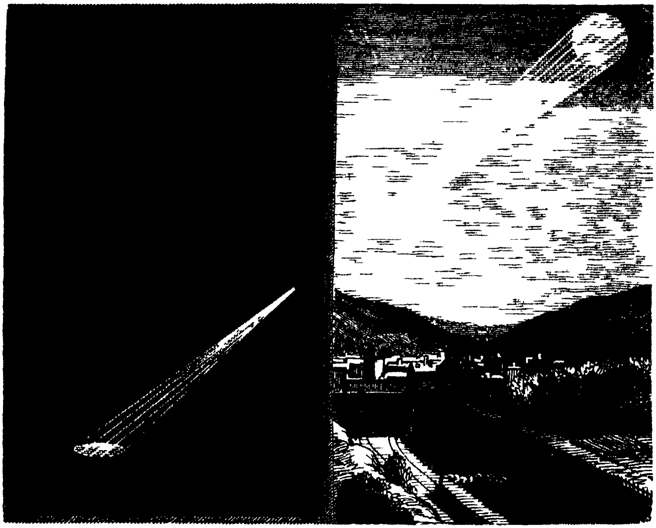


Fig 349

The images formed in the camera obscura have the peculiarity of being independent of the shape of the aperture through which the rays enter, *provided this is very small*, that is, that, whether this aperture is round, square, or triangular, the image formed on the screen is always a faithful reproduction of external objects, and not of the hole made in the shutter To account for this phenomenon let us consider the case of a pencil of sunlight of any shape whatever passing into a dark room (fig 349) Compared with the magnitude of the sun, this hole is really nothing more than a point, whence it

follows, that the whole of the rays which traverse it represent an immense luminous cone, of which the hole is the summit and the sun the base. By their being prolonged into the chamber these rays give rise to a second cone resembling the first, but far smaller ; and if this second cone falls upon a screen which is perpendicular to the straight line joining its summit to the centre of the sun, it produces on this screen a circular image like the sun. If the screen is obliquely inclined towards this line, as represented in fig. 349, the

Fig. 350.

image is elongated, but it never has the shape of the aperture unless the screen is very close.

In the same manner we must explain the luminous circles formed on the ground under an avenue of trees illuminated by the sun. Whatever be the shape of the spaces in the foliage through which the light passes, a circular image of the sun is projected upon the ground (fig. 350).

388. **Rectification of images of the camera obscura.**—When a monument or a landscape is to be reproduced in a camera obscura, the image must be rectified. For this purpose the apparatus is arranged as in fig. 351. A little above the hole through which the light enters, a plane mirror is placed, inclined so as to send the rays towards a condensing lens fixed at the end of a tube. Below this

lens and at its focus is placed a white screen, on which external objects depict themselves. The images thus obtained, rectified by the reflection of the rays from the plane mirror and their passage through the lens, are not merely admirable from their fidelity and colour, but they do what no other kind of reproduction can do—they reproduce motion. If the camera obscura is set up in front of a promenade, or a public place, the images of the passers-by are seen

Fig. 351.

to move across the screen, and reproduced with such fidelity that they can be recognised.

The camera obscura gives in this manner an amusing spectacle. It may, moreover, be used in drawing, for even a person who cannot draw can trace with a pencil the outlines of the image on a screen. For this latter purpose the following arrangement is usually adopted.

389. **Portable camera obscura.**—To use the camera obscura for producing views, it should be light and portable, and should not occupy too large a space. Fig. 352 represents a simple and convenient form of the apparatus. It consists of a wooden tripod, supporting a board of the same material, and surrounded by a curtain which forms a small tent, in which the artist places himself. In the centre of the tent is a small table resting on a tripod, on which is produced the image. At the top of the apparatus, in a brass tube open at the side, is a glass prism, which produces the

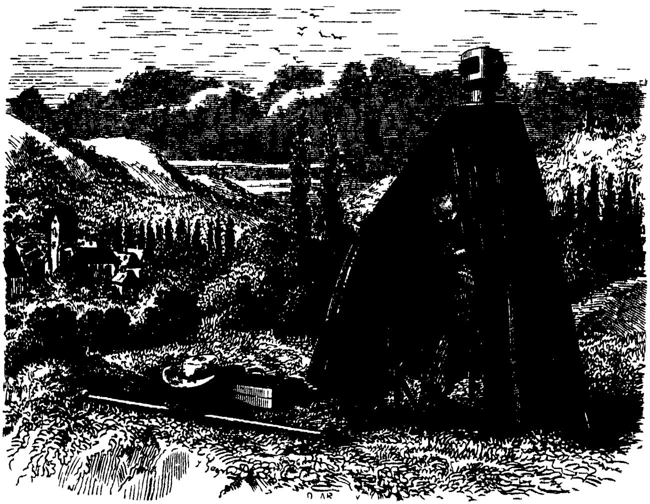


Fig 352

effect both of the inclined mirror and of the lens in the camera obscura described above. For this purpose the first face of the prism is convex, as represented in fig. 353. Hence on passing into this prism the rays from a distant object converge ; then undergoing a total reflection on the side *m* (340), they are sent towards the third face, which is concave, whence they emerge with the same degree of convergence that they had before traversing the lens, and there is thus reproduced at *ab* on the table P the image of the object AB, from which they come. The designer takes then the outlines of this image on a sheet of paper. This apparatus is

now but seldom met with; it has been quite superseded by the use of the camera obscura in photography (390).

390. **Photography.**—*Photography* is the art of fixing the images of the camera obscura on substances *sensitive* to light. The various photographic processes may be classed under three heads: photography on metal, photography on paper, and photography on glass.

Wedgwood was the first to suggest the use of chloride of silver in receiving the image; and Davy, by means of the solar microscope, obtained images of small objects on paper impregnated with chloride of silver; but no method was known of preserving the images thus obtained, by preventing the further action of light. Niepce, in 1814, obtained permanent images of the camera by coating glass plates with a layer of varnish composed of bitumen dissolved in oil of lavender. This process was tedious and inefficient, and it was

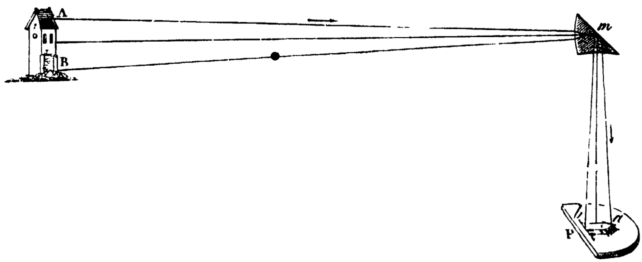


Fig. 353.

not until 1839 that the problem was solved. In that year, Daguerre described a method of *fixing* the images of the camera, which, with the subsequent improvements of Talbot, Archer and others, has rendered the art of photography one of the most marvellous discoveries ever made, whether as to the beauty and perfection of the results, or as to the celerity with which they are produced.

Fig. 354 gives a vertical section of the kind of camera obscura used by photographers. It consists of a rectangular wooden box in two pieces, one of which, C, is fixed, and the other, B, can be pushed in or out like a drawer. In the front of the box, C, is a brass tube, A, in which is a condensing lens, L, which is fixed. In A is a second tube, which can be moved backwards or forwards by a rack and pinion moved by the milled head, D. In this second tube is a second lens L′, which, by the motion of the tube, is brought nearer to or further from the lens, L. The combination of the two lenses

forms what is called an object-glass with combined lenses. The advantage of this arrangement is, that it works more rapidly than an object-glass with a single lens, has a shorter focal distance, and can be more readily focussed.

On the face of the box opposite the object-glass is a screen of ground glass, E, which can be moved backwards and forwards at will, and on which a reversed image of the object is formed. Thus, if a portrait is to be taken, the person is placed at a distance of three or four yards from the camera, which is then adjusted until the image is formed in the proper position on the glass. It is next placed in exact focus by slowly approaching or removing the lens L′. The glass is contained in a frame which can be easily removed and replaced by the slide containing the material on which the photograph is to be taken.

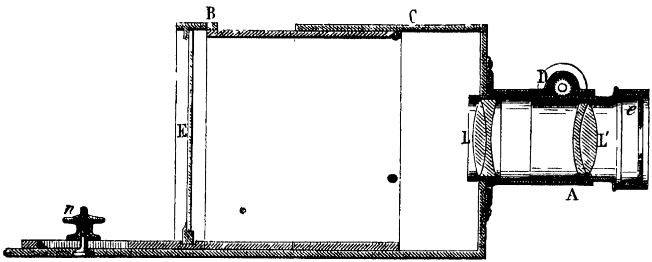


Fig. 354

The photographs on metal, or *daguerreotypes*, so called from Daguerre the inventor, are now seldom used. The photographic methods in glass and paper are infinitely varied, not as regards the optical part, but as concerns the substances employed, and therefore as regards the chemical reactions involved. We will content ourselves with describing the ordinary method of taking a portrait on paper.

For this purpose what is called a *negative* must first be taken—an inverse image of the object, that is to say, in which the light parts are dark, and *vice versâ*. With this view a glass plate is coated with a thin layer of *collodion* (gun-cotton dissolved in ether), containing a certain quantity of iodide of potassium. The plate thus coated is then placed in a solution of nitrate of silver. By the chemical reaction between the iodide of potassium and the

nitrate of silver a coating of iodide of silver is formed on the plate, which is sensitive to light, and hence this operation must be performed in a dark room. The plate is then placed in the slide, and inserted in the camera instead of the focussing-glass. The slide is so constructed that the plate can be instantaneously exposed to or cut off from the action of light. After exposure for a suitable time, the slide is removed to a dark room. No change is visible in the plate, but on pouring over it a solution called the *developer*, an image gradually appears. The principal substances used for developing are protosulphate of iron and pyrogallic acid. The action of light on iodide of silver produces some change, in virtue of which the developers have the property of reducing to the metallic state, those parts of the iodide of silver which have been most acted upon by the light. When the picture is sufficiently brought out, water is poured over the plate, in order to prevent the further action of the developer. The parts on which light has not acted are still covered with iodide of silver, which would also be affected if the plate were now exposed to the light. It is accordingly washed with solution of hyposulphite of sodium, which dissolves the iodide of silver and leaves the image unaltered. The picture is then washed, dried and coated with a thin layer of spirit-varnish to protect it from mechanical injury.

When once the negative is obtained, it may be used for printing an indefinite number of positive pictures. For this purpose, paper is impregnated with chloride of silver, by floating it first on a solution of chloride of sodium and then, when dry, on one of nitrate of silver; chloride of silver is thus formed on a paper by double decomposition. The negative is placed on a sheet of this paper in a copying frame, and exposed to the action of light for a certain time. The chloride of silver becomes acted upon—the light parts of the negative being most affected, and the dark parts least so. A copy is thus obtained, in which the lights of the negative are replaced by shades, and conversely. The picture is next immersed in a bath of chloride of gold, by which those parts on which the light has acted become coated with gold; and, according to the extent to which the process is carried, different shades of colour are produced. The picture still contains some unaltered chloride of silver which would be changed if it were now exposed to the action of light; and to *fix* it, the picture is immersed in a solution of hyposulphite of sodium, which dissolves the unaltered chloride of silver. Finally the picture is well washed with pure water, which

dissolves out the hyposulphite of sodium and all other soluble salts.

391. **Dry Plates.**—The possibilities of photography have been greatly increased by the rapid development of what are known as

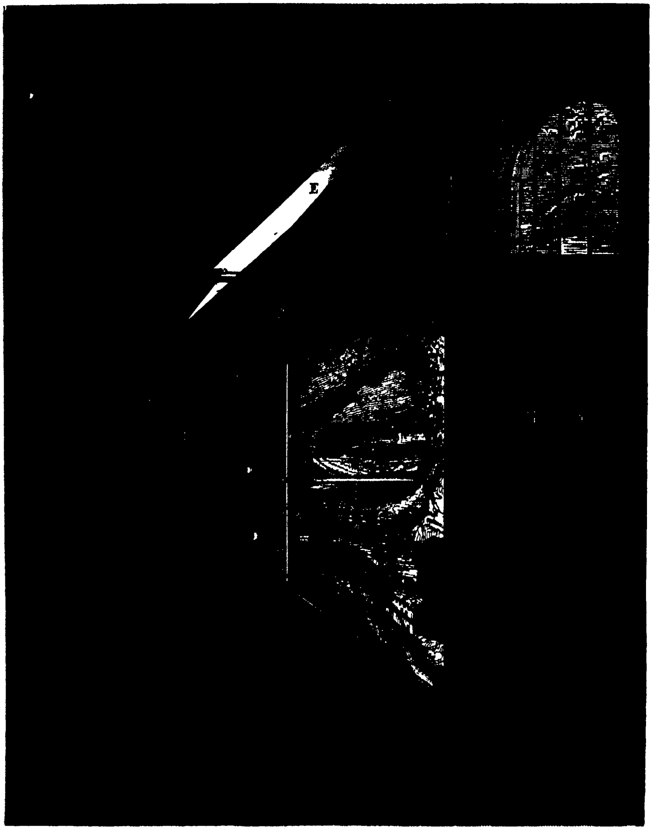


Fig. 355

dry plates. These are made from an emulsion consisting essentially of gelatine with which is incorporated bromide of silver. Glass plates are coated with emulsion, and are then dried. By varying

the composition of the mixture, and by care in manipulation, plates may be obtained which produce pictures of great beauty, and require but a small fraction of a second for their exposure. Such plates will keep for months, and even years, and may even be kept for a long time before development. For travellers more especially this is an improvement of the greatest value and importance.

392. **Diorama.**—The name *diorama* is derived from two Greek words which signify *viewed through*, and is applied to pictures painted on muslin or on calico, so as to represent two opposite effects, like the polyorama, according as the pictures are seen by reflection or by transmission.

The picture is arranged vertically in a dark room, as represented in fig. 355. The first effect, that painted on the front of the cloth, is illuminated by reflection : the second, that painted behind, is illuminated by transmission. With this view light enters through a window, M, in an upper story, and is sent to a screen, E, which reflects it towards the picture, and lights it from the front ; behind the picture is another window, N, which, when open, lights it behind. The shutters, NN, being closed, the spectators first see the subject on the front of the cloth. By a simple arrangement, a shutter, A, which slides without noise in two grooves, is made to advance, and when the picture is scarcely illuminated, the shutters, NN, are opened, and then the picture painted on the other side of the cloth gradually appears through it, and is substituted for the former one.

The diorama was invented by Daguerre, who had great skill in this kind of painting. The figure represents the valley of Goldau before the terrible landslip which took place on September 2, 1806. At the moment light was intercepted by the screen, lightning flashed, thunders roared, and there were all the effects of a violent storm. On the return of day, the rocks had given way, the lake had been partly filled up, and the chalet destroyed ; in short, the image of ruin and desolation was reproduced with astounding fidelity.

393. **Ghost scenes.**—We will give here a description of a curious optical effect, which was first introduced some years ago in the theatres under the name of *ghost scenes*.

In order the more readily to understand the appearance of these spectres, let us recall an effect which everyone has observed. When on a railway journey, towards evening, we look at the windows of carriage doors, we see a pale and indistinct image of the travellers inside. This is an effect of reflection from the panes, which reflect

the light that illuminates persons and objects placed in the compartment ; and the faint light of the images, arises from the fact

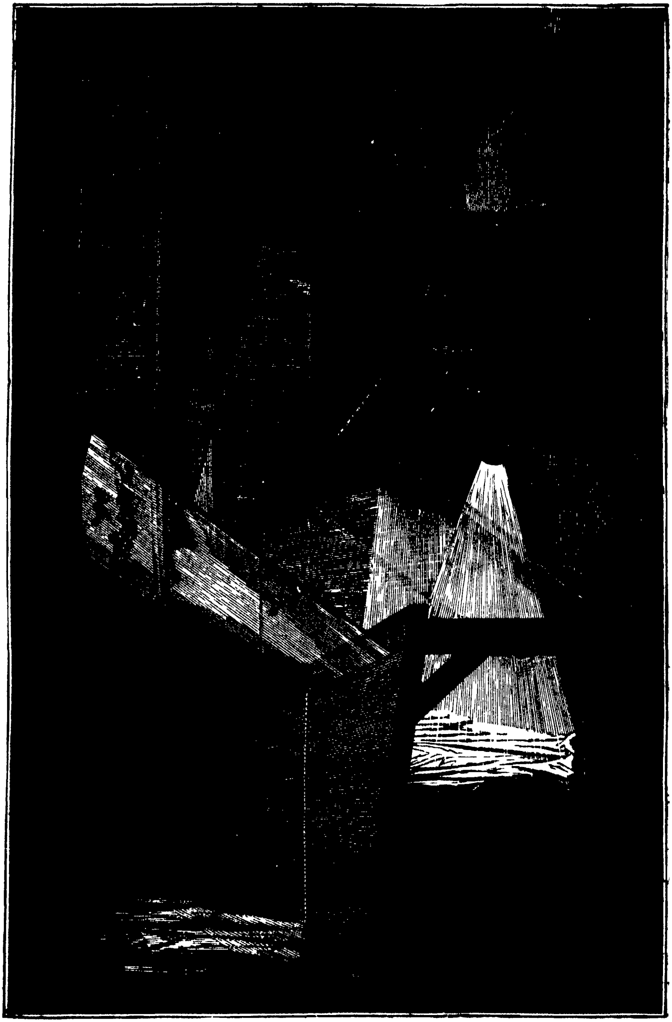


Fig. 356

that the panes, allowing great part of the light to be transmitted, send very little towards the observer. A similar effect is produced when in the evening, in a well-lighted street, a window front, which is little or not at all lighted, is looked at. The observer sees his own image and that of the passengers on the other side of the panes. These effects are not seen in full daylight, for the images which tend to be reproduced are effaced by the brightness of the light.

These effects have been utilised in public to simulate the appearance of ghosts. Fig. 356 represents the arrangements of the apparatus intended for this purpose. On the floor of the stage not seen by the spectators, is an actor covered by a sheet, and intended to represent the ghost. Between the actor and the public is a magic lantern, illuminated by limelight or by the electric light, so as to give an extremely bright illumination. An assistant directs the light upon the actor, and the white cloth, thus powerfully illuminated, sends its rays towards an inclined plate of glass, placed near the assistant. This glass, which is silvered, sends almost all the reflected light towards a second plate which is not silvered, on the same scene. This latter plate acts like those in carriages and in show windows, which we have mentioned above, and, being traversed by the greater part of the incident rays, sends but little light towards the spectators. Yet, as during this time care is taken that the illumination in the room is very faint, the light is sufficient to give a cloudy image of the actor placed under the stage.

If another actor enters the scene the public see very distinctly through the glass, which is carefully concealed by hangings and decorations; and if this actor is behind the plate at the same distance as the image, he can join his action with that of the ghost, and thus produce a complete illusion.

The same effects are produced with a single plate, but, as its obliquity tends to give inclined images, to rectify them the actor under the theatre must hold himself so much inclined as to render his play very difficult. With the two plates represented in the above figure, the actor retains his natural position.

VISION AND STEREOSCOPE.

394. **Structure of the eye and mechanism of vision.**- Although the description of the eye belongs to physiology rather than to physics, we may give an account of this organ, which is not merely a true optical instrument, but one of great perfection; it

has, for instance, the remarkable property of spontaneously adapting itself to see distinctly at various distances, which the best optical instruments cannot do.

The eye is almost spherical in shape, and is surrounded by several membranes, which fig. 357 represents open from back to front. The front part of the eye is a perfect transparent membrane *c*, called the transparent cornea, and which is commonly called the *white of the eye.* At a small distance behind the cornea is a membranous diaphragm *hi*, called the *iris* : it constitutes the variously coloured disc which appears in the middle of the white of the eye, and to which is due the colour. In the centre of the iris is an aperture called the *pupil* ; in man this is circular, and in the cat narrow and elongated, and through it rays pass into the eye. Behind the iris, but very near it, is the *crystalline lens*, *o*, or briefly crystalline, which is a transparent mass, having the shape, and fulfilling the functions of a double convex lens. The whole of the

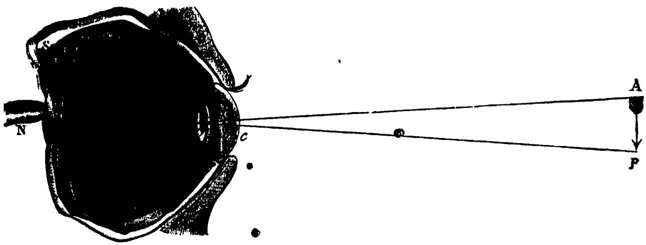


Fig. 357.

hinder part, from the crystalline to the back of the eye, is filled with a gelatinous transparent mass, like white of egg, which is called the *vitreous humour.* In front of the eye, between the crystalline and the cornea, is a perfectly transparent liquid called the *aqueous humour.* The whole of the back inside part of the eye is lined with a soft, whitish, transparent membrane, R, called the *retina* ; it is the extension of a nerve, N, which proceeds to the brain, and transmits the sensation of vision, whence it receives the name *optic nerve.* Behind the retina is a second membrane, C, called the *choroid*, which is impregnated by a black matter, that absorbs all rays which should not co-operate in producing vision. Lastly, a membrane, S, the *sclerotica*, surrounds the whole eyeball behind, and joins the transparent cornea in front.

These details being known, we may readily account for the

mechanism of vision ; for the eye is in fact a small camera obscura (387), of which the pupil is the aperture, the crystalline is the condensing lens, and the retina is the screen on which the image is formed. The optic nerve, carrying from thence to the brain the impression produced by the vibrations of the luminiferous ether on the nervous system of the retina, enables us to perceive external objects. In accordance with this explanation we should see objects reversed, and not in their natural position. The inversion of images in the eye has greatly occupied both physicists and physiologists, and many theories have been proposed to explain how it is that we do not see inverted images of objects. Some have supposed that it is by custom, and by a regular education of the eye, that we see objects in their true position ; that is to say, in their position relative to us. The visual impression becomes corrected by the impression of other senses, such as that of touch. Müller, Volkmann, and others have contended that, as we see everything inverted, and not simply one object among others, nothing can appear inverted, because terms of comparison are wanting. It must, however, be admitted that none of these theories is quite satisfactory.

395. **Distance of distinct vision. Accommodation. Short and long sight.**—We know that in double convex lens the distance of images from the lens increases or diminishes as the object is approached or receded (347). Hence, according to the distance of the objects looked at, it would seem that the image formed by the crystalline should be sometimes formed exactly on the retina, and sometimes a little in front of or behind this membrane. Only objects placed at a certain distance should then be seen distinctly ; all those nearer or further should appear confused.

Experience shows us, however, that the eye can see distinct images of objects at very different distances. We can, for example, see a distant tree through a window, and also a scratch on the pane, though not both distinctly at the same moment ; for when the eye is arranged to see one clearly, the image of the other does not fall accurately upon the retina. An eye completely at rest seems adapted for seeing distant objects ; the sense of effort is greater when a near object is looked at, after a distant one, than in the reverse case.

The power which the eye possesses of voluntarily adapting itself, so that it can form distinct images on the retina of objects at very different distances, is called its power of *accommodation.*

When the eye is adjusted for a near object, by means of pressure

exerted by the muscles of the eye, the entire crystalline lens is pushed forward, and both the front and back surfaces are made more convex, especially the former. When the eye has been adjusted for a distance the pressure is relaxed, the lens becomes flatter, and recedes a little.

Yet, though the eye can well distinguish objects at very different distances, there is, in the case of each person, a distance at which objects are more distinctly seen than at any other. This distance is called *the distance of distinct vision* ; it varies with different persons, and often in different eyes in the same individual ; for small objects like print it is usually about ten or twelve inches.

In order to obtain an approximate measurement of the least distance of distinct vision, two small parallel slits are made in a card at a distance of 0·03 of an inch. These apertures are held close before the eye, and when a fine slit in another card is held very near them, the slit is seen double, because the rays of light

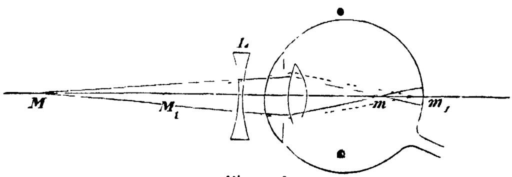


Fig. 358.

which have traversed both apertures do not intersect each other on the retina, but behind it. But, if the latter card is gradually removed, the distance is ultimately reached at which both images coincide and form one distinct image. This is the distance of distinct vision. Stampfer constructed an *optometer* on the principle of this experiment, which is known as *Scheiner's experiment.* The distance of distinct vision may also be determined by viewing a tightly stretched thread and observing at what distances it appears as a line, and at what it widens owing to its not being seen sharply.

Those who can only see well at shorter distances have a defect in the shape of the eye ; they are said to be *myoptic* or *short-sighted*, from two Greek words which signify *close* the eyes ; for myoptic persons, in order to see more distinctly, do in fact involuntarily half-close the eyes. If the distance of distinct vision is greater than ten or twelve inches, that is also due to a malformation of the eye, and those affected by it are called *presbyoptic* or *long-sighted*, from a

Greek word which signifies *aged*, for this defect is usually met with in aged persons.

Myopy, or short-sight, results from too great a convexity of the cornea, or of the crystalline. The eye being too convergent, the rays of light from an object, M, for instance, are refracted in such a manner that, instead of forming their focus exactly on the retina, they form it a little in front, at m (fig. 358), and therefore the image which this membrane perceives is confused. But if objects are approached to the eye, as at M_1, the image recedes, and is formed exactly on the retina m, when the objects are sufficiently near, which explains why short-sighted persons only see objects when they are very close. They can also see more distinctly by contracting the pupil, or by looking through a small hole perforated in a card; for then, as the diameter of the luminous pencil which penetrates into the eye is less, the rays mainly penetrate the crystalline at the centre, and, being therefore less affected by its excess of convexity,

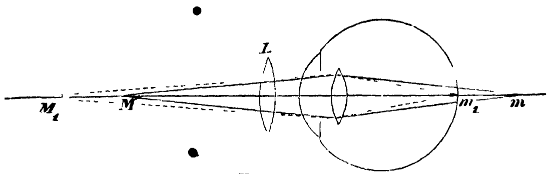


Fig. 359.

they form the focus at a greater distance. Myopy is mainly met with in young people: as they grow older, the convexity of the eye diminishes, so that their sight generally becomes better when that of other people becomes worse.

Presbytism, or long-sight, is due to the flattening of the crystalline; as the eye is then no longer sufficiently convergent, the rays from M (fig. 359), instead of forming their focus on the retina, tend to form beyond it at m, whence it arises that the eye only observes a confused image. But, as the object recedes, as at M_1, the image comes nearer the crystalline, and is ultimately formed exactly on the retina, when objects are sufficiently distant; this is the reason why long-sighted persons see objects most distinctly when they are distant.

Short-sight is remedied by the use of concave or diverging lenses before the eyes (fig. 358); as the pencil is spread out before entering the eye, the focus m of the crystalline is receded by the action of these glasses, as far as the retina m_1, provided the degree of divergence

of the glasses is suitably adapted to the excess of convexity of the crystalline. For far-sight, on the contrary, condensing or convex lenses should be used (fig. 359), so as to correct the want of convexity of the crystalline. As the rays then become more convergent before entering the eye, the image, which would otherwise be formed beyond the retina at *m* (fig. 359), approaches it, and is ultimately formed exactly upon it.

For a long time double concave lenses were exclusively used for short-sight, and double convex for far-sight. The concavo-convex lenses represented in O, fig. 300, are recommended for long sight, and those in R (fig. 301) for short sight. These are called *periscopic glasses*, from two words meaning *to see round*; for as their shape better enables them to embrace the eyeball, they facilitate vision in all directions; and, as they do not deform objects, they do not fatigue the eye like other glasses.

396. **Binocular vision.**—Although we have two eyes, and when we fix them on the same object each forms its own image upon the retina, yet we only see one object, just as with two ears we only hear one sound. Various hypotheses have been made to account for single vision with two eyes. Some have considered it as an effect of habit; others assigning to it a physiological cause, have assumed that two points similarly placed on the two retinas correspond to the same nervous filament which, coming from the brain, bifurcates towards each eye. Hence the two impressions simultaneously produced on the two retinas result in a single sensation.

Not only does simultaneous vision with two eyes enable us to see bodies with greater lustre, the imperfections of one eye are corrected by those of the other; it also gives us the impression of relief, as the stereoscope well shows, and it is a most important aid in estimating the distance and magnitude of objects.

397. **Stereoscope.**—The *stereoscope*, so called from two Greek words which mean *perception of solidity*, is an ingenious instrument, which was invented by Sir C. Wheatstone, and modified to its present form by Sir D. Brewster.

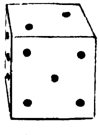


Fig. 360.

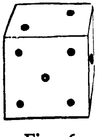


Fig. 361.

To understand the effect of the stereoscope, let us observe that when we look at an object with two eyes, each eye does not see it under exactly the same aspect, but under a slightly different perspective. Thus let a small object, such as a dice, be successively

viewed with one eye, at a slight distance, without moving the head. If the cube be just in front of the observer, looking at it with his left eye, he will see the face, and a small portion of the left side, the other being concealed (fig. 360); if, on the contrary, he views it with his right eye, he sees the front and a portion of the right side, the other being hidden (fig. 361). Thus the two images formed on the retina are not quite identical, for each corresponds to a different point of view. It is this difference in the images which gives us the sensation of relief in bodies, and enables us to appreciate their shape and their distance.

This may be confirmed by making two drawings of the same object, taken respectively with the perspective belonging to the right and to the left eye; then, as each eye looks separately at the drawing through prisms or lenses, which make the two drawings coincide, by giving the rays of light the same direction as if they converged from a single object, the impressions produced upon each retina will be the same as if the object itself were viewed. The illusion is in fact so complete that, however prejudiced we may be, it is impossible not to be deceived, so true are the effects of relief and perspective.

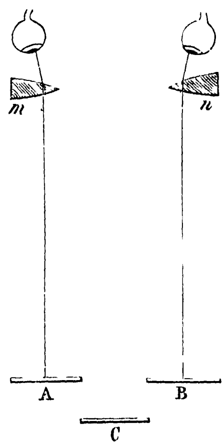


Fig. 362.

This is the principle of the stereoscope. Fig. 362 shows the path of the rays of light in the instrument. At A is the drawing of the object seen with the left eye; at B that of the same object seen with the right. The rays from these images fall on two lenses *m* and *n*, and take, after having traversed them, the same direction as if they came from the point C; the object represented at A and B appears in relief at this spot.

The lenses *m* and *n* must impart exactly the same deviation to the rays, and they should therefore be exactly identical Brewster attained this result by cutting in two halves a double convex lens, and placing the right half in front of the left eye and the left half in front of the right eye, as shown in fig. 362.

To produce the sensation of relief, the two dissimilar images at A and B should give from two different points of view so faithful a

representation of the same object that these separate views cannot be taken by the hand. And it is only practicable by means of photography. Fig. 363 represents two photographs of Sir C. Wheatstone taken at a slightly different angle. That of the left represents

Fig. 363.

more of the full face, and must be looked at with the left eye; the other one is more in profile, and must be viewed with the right eye. These two views being placed in the stereoscope disappear for each observer, for then the two sensations special to each eye coalesce, and form a single image, as represented in fig. 364, and the original appears so solid, with such perfect relief, that the imagination can with difficulty realise the fact that we are only concerned with a drawing on a plane surface.

If the position of the pictures be reversed—that is, if the right-hand picture is viewed with the left eye, and *vice versâ*—the elevations of the pictures appear as depressions, and the depressions as elevations; thus the image produced is that of an intaglio. Such pictures are called *pseudoscopes* (ψευδής, false).

When objects seen in the stereoscope are of different colours, the impression produced is not the same as that of either of them. Thus, red and green coalesce to form a kind of shot colour or mixture of the two.

If two pictures are absolutely identical they form a perfectly flat picture in the stereoscope. If, however, there are minute differences, the eyes make movements in order to combine the two

images, and there is formed a stereoscopic picture This process has been used to distinguish between forged and genuine bank notes, between two different editions of the same printed work, and the like

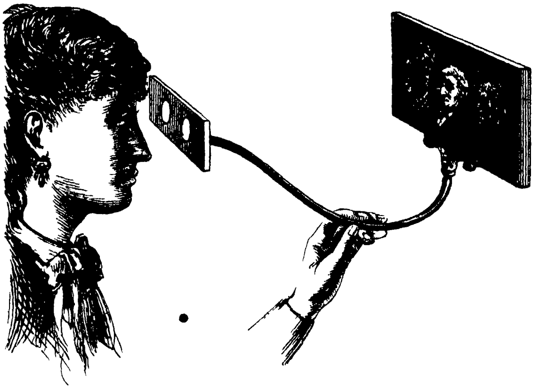


Fig 364

That binocular vision is of great service in the exact appreciation of distance, is seen from the difficulty we experience in threading a needle when one eye is closed

BOOK VII.

ON MAGNETISM.

CHAPTER I.

PROPERTIES OF MAGNETS.

398. **Natural and artificial magnets.**—Natural magnet, or *lodestone*, is a mineral which has the property of attracting iron and a few other metals, especially nickel and cobalt. This mineral is an oxide of iron ; that is, a compound of iron and oxygen.

Lodestone has another property, which is not less remarkable—namely, that when it is balanced on a pivot, or suspended to a thread, or placed on a cork which floats on water, it constantly points towards a certain direction of the horizon ; by which property this mysterious stone, which is of a dull colour, and has no lustre, deserves a place above the most valuable precious stones ; for, like a new Ariadne's thread, it guides mariners in darkness, and enables them to steer with something of the same certainty on sea as on a travelled road.

This lodestone, or magnetic stone, was known to the ancients, who called it Lydian stone, or Magnesian stone ; for it was first found near a village of this name in Lydia. And from this place, Magnesia, the Greeks derived the name *magnes*, from which is obtained the word magnetism, under which name philosophers understand the whole of the properties which magnets possess. Magnetic iron ore is very abundant in nature ; it is met with in the older geological formations, especially in Sweden and Norway, where it is worked as an iron ore, and furnishes the best quality of iron.

Besides natural there are also *artificial* magnets, so called from their being produced by art. They are usually made of steel. When steel is *tempered*—that is, when it is raised to a high temperature, and suddenly cooled by being immersed in cold water—

it acquires great hardness; and it is in virtue of this property that it becomes so valuable for cutting instruments. Steel has not naturally the power of attracting iron; but when it is tempered and made hard this property may be imparted to it by rubbing it with a powerful magnet either natural or artificial; and it then becomes itself a permanent magnet.

Artificial magnets have just the same properties as natural ones, but are far more powerful and convenient; they are, accordingly,

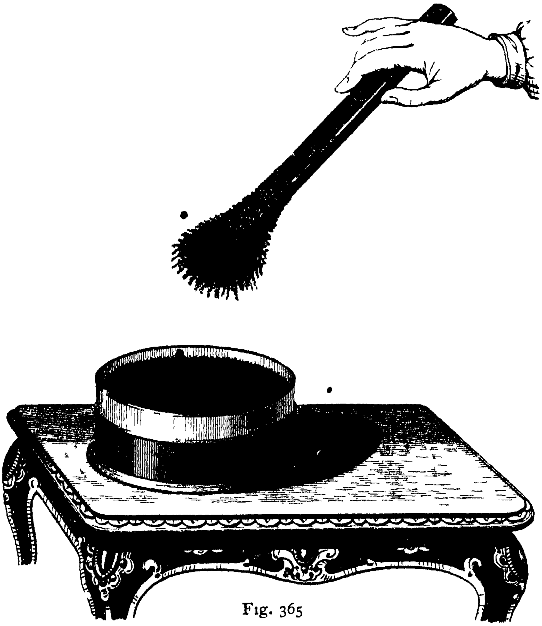


Fig. 365

almost universally used in experiments. They are sometimes made into bars a foot or two long, like those represented in fig. 377; sometimes in a horseshoe form (fig. 378); or lastly, if they are to be movable, they are cut out of a thin sheet in the shape of a lozenge, as shown in fig. 367. A small agate cup is let into the centre in such a manner that the needle can rest on a vertical pivot and oscillate freely in a horizontal plane. Thus arrranged, the artificial magnet becomes a *magnetic needle*.

399. **Distribution of magnetic force in magnets.**—The force with which a magnet attracts iron is not everywhere the same. The greatest attraction is at the ends : it decreases rapidly from there towards the middle, where there is no attraction. For, if a magnetised bar is immersed in iron filings, when it is withdrawn the filings are seen to adhere to the ends in long and compact filaments (fig. 365), but not a particle adheres to the middle.

The two points near the ends where the attraction is most powerful are called the *poles* of the magnet, and the medial part where there is no attraction is called the *neutral line*. All magnets, natural or artificial, have each two poles and a neutral line. Sometimes, besides the two principal poles, there are observed inter-

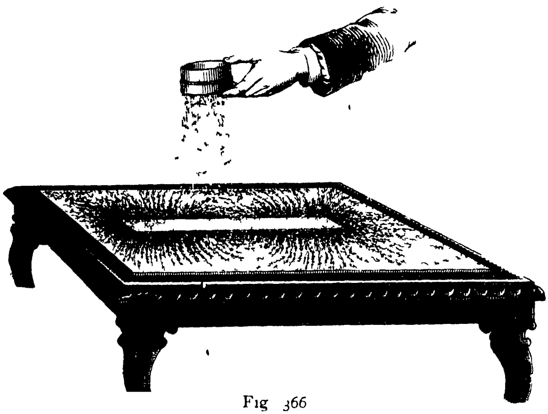


Fig 366

mediate poles, which are called *consequent poles*. This arises from some inequality in the temper of the steel, or in the manner in which the bar has been magnetised. We shall always assume that magnets being properly magnetised have only two poles.

The action of magnets upon iron is exerted through all bodies which are not themselves magnetic. Thus, a magnet being placed on a table and a piece of cardboard rested upon it, iron filings are allowed to fall through a sieve (fig. 366). As the filings fall, acted upon by the two poles, they become arranged in long filaments, which group themselves along curved lines from one pole to the other ; but over the middle of the magnet no action is observed, and the filings are arranged as they would be upon any other substance.

400. **Laws of magnetic attraction and repulsion.**—When the two poles of a magnet are compared as to the action they exert upon iron, they seem to be completely identical ; this identity is, however, only apparent : for, if to the same pole of the magnetic needle (fig. 367) the two poles of a bar magnet held in the hand be successively presented, the curious phenomenon is observed that, if the pole *a* of the needle is attracted by pole B of the bar, it is, on the contrary, repelled by the other pole A of the latter ; which shows that the poles of the bar are not exactly identical, for one repels the pole *a*, while the other attracts it. The same difference

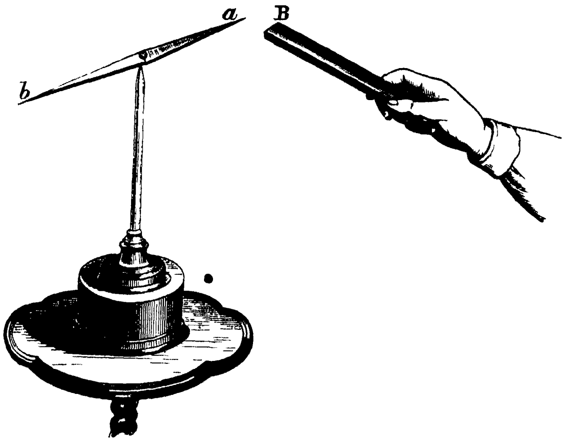


Fig 367

may be ascertained to exist between the two poles of the needle *ab* ; for if the same pole, B, of the bar be successively presented to the two ends of the movable needle, in one case there is repulsion, in the other attraction.

We shall presently see that a freely suspended magnet always sets with one pole pointing to the north, and the other towards the south. The end *pointing towards the north* is called in this country the *north pole*, and the other end is the *south pole.* The end of the magnetic needle pointing to the north is sometimes called the *marked end of the needle.* Hence, in reference to magnetic attraction and repulsion, the following law may be enunciated :—

Poles of the same name repel, and poles of contrary name attract, one another.

The opposite actions of the north and south poles may be shown by the following experiment :—A piece of iron, a key for example, is supported by a magnetised bar, A (fig. 368). A second magnetised bar of the same dimensions, B, is then moved along the first, so that their poles are contrary. The key remains suspended so long as the two poles are at some distance, but when they are sufficiently near, the key drops just as if the bar which supported it had lost its magnetisation. This, however, is not the case, for the key would be again supported if the first magnet were presented to it after the removal of the second bar.

The attraction which a magnet exerts upon iron is reciprocal, as is easily verified by presenting a mass of iron to a movable magnet, when the latter is attracted.

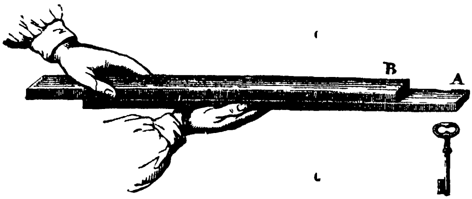


Fig. 368.

401. **Hypothesis of two magnetic fluids.**—In order to explain the phenomena of magnetism, the existence of two hypothetical *magnetic fluids* or magnetisms has been assumed, each of which acts repulsively on itself, but attracts the other fluid. The fluid whose resultant effects predominate at the north pole of the magnet is called the *north* or *boreal* fluid, and that at the south pole, the *south* or *austral* fluid. Sometimes the terms *positive* and *negative* are employed, corresponding to the north and south magnetisms.

It is assumed that, before magnetisation, these magnetisms are combined in each molecule, and mutually neutralise each other ; they can be separated by the influence of a force greater than that of their mutual attraction, and can arrange themselves in a certain definite position about the molecules to which they are attached, but cannot be removed from them.

The hypothesis of the two fluids is convenient in explaining magnetic phenomena, and will be adhered to in what follows. But it must not be regarded as anything more than an hypothesis, and

it will afterwards be shown that magnetic phenomena can also be explained by assuming that they result from electrical currents circulating in magnetic bodies.

402. **Influence of magnets upon magnetic substances.**—Magnetic substances are substances containing the two magnetisms, but in the neutral state; that is to say, holding each other in check by their reciprocal action: such substances are iron, steel, and to a far less extent nickel and cobalt. Magnets also contain the two magnetisms; but there is between them and magnetic substances this difference, that in magnets the two magnetisms in each molecule are separated, and each produces a separate effect; while in magnetic substances the magnetisms are combined and produce no effect.

A magnetic substance is readily distinguished from a magnet. The former has no poles; if successively presented to the two ends of a magnetic needle, *ab* (fig. 367), it will attract both ends equally, while one end of a magnet would attract the one, but repel the other, end of the needle. Magnetic substances also have no action on each other, while magnets attract or repel, according as unlike or like poles are presented to each other.

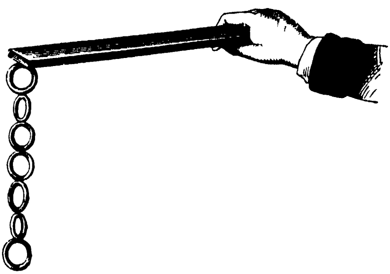


Fig. 369.

When a magnetic substance is placed in contact with the poles of a magnet—the north pole, for instance—this acting attractively on the south magnetism of the substance, and repelling the north magnetism, it follows that in this body a separation of the two is effected, or, in other words, a true magnet is produced. For, if any piece of soft iron, an iron ring for example, be presented, to a magnetised bar, not merely is this ring supported (fig. 369), but it acquires the property of supporting the second; then this second a third, and so forth. Remove the bar, and the invisible link which unites this marvellous chain is broken, and the rings separate.

This action, in virtue of which a magnet can develop magnetism in iron, is called *magnetic induction* or *influence*, and it can take place without actual contact between the magnet and the iron, as

is seen in the following experiment:—A bar of soft iron is held with one end near a magnetic needle. If now the north pole of a magnet be approached to the other end of the iron bar without touching it, the needle will be attracted or repelled, according as its south or north pole is near the bar. For the north pole of the magnet will develop south magnetism in the end of the bar nearest it, and therefore north magnetism at the other end, which would thus attract the south, but repel the other end of the needle. Obviously if the other end of the magnet were brought near the iron, the opposite effects would be produced on the needle.

The soft iron also becomes magnetised by induction when in the neighbourhood of the magnet; the action is the same in kind as when the bodies are in actual contact, but is not so strong. In this respect there is a wide difference from the communication of electricity to an unelectrified body.

Magnetic induction explains the formation of the tufts of iron filings which become attached to the poles of magnets. The parts in contact with the magnet are converted into magnets; these act inductively on the adjacent parts, converting them into magnets, these again on the following ones, and so on, producing a threadlike arrangement of the filings.

403. **Coercive force.**—We have seen from the above experiments that soft iron becomes instantaneously magnetised under the influence of a magnet, but that this magnetisation is not permanent and ceases when the magnet is removed. Steel likewise becomes magnetised by contact with a magnet, but the operation is effected with difficulty, and the more so as the steel is more highly tempered. Placed in contact with a magnet, a steel bar acquires magnetic properties very slowly, and, to make the magnetism complete, the steel must be rubbed with one of the poles. But this magnetisation, once evoked in steel, is permanent, and does not disappear when the inducing force is removed.

These different effects in soft iron and steel are ascribed to a *coercive force*, which, in a magnetic substance, offers a resistance to the separation of the two fluids, but which also prevents their recombination when once separated. In steel this coercive force is very great, in soft iron it is very small, or even quite absent when the iron is very carefully prepared. By straining, hammering, or twisting a certain amount of coercive force may be imparted to soft iron, as will be explained under Magnetisation (408).

CHAPTER II.

TERRESTRIAL MAGNETISM. COMPASSES.

404. **Directive action of the earth on magnets.**—The power of attracting iron is not the only one which magnets present; they have also that of setting in a certain definite direction, when they can turn freely in a horizontal plane. Thus, when a magnetised needle is placed on a pivot on which it can turn freely (fig. 370), it ultimately sets in a position which is more or less north and south. If removed from this position, it always returns to it after a certain number of oscillations.

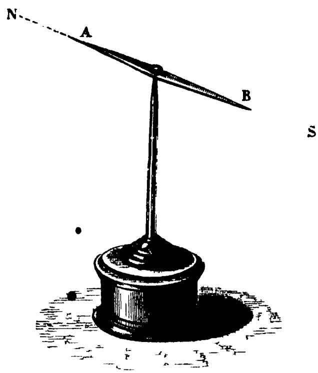


Fig 370.

If, instead of placing the needle on a pivot, it be placed on a cork, and this in turn be floated on water, the needle will after a few oscillations come into a position which is the same as that it had on the pivot; that is, nearly north and south. It is important in this second experiment to observe that the needle only sets in a certain direction, and that, though free to make either a forward or a backward motion, it remains in the middle of the vessel, and moves neither towards the north nor the south: hence the force which acts upon the needle is simply *directive*, and not attractive.

Analogous observations have been made in different parts of the globe, from which the earth has been compared to an immense magnet, whose poles are very near the terrestrial poles, and whose neutral line virtually coincides with the equator.

The polarity in the northern hemisphere is called the *northern* or *boreal* polarity, and that in the southern hemisphere the *southern* or *austral* polarity. In French works the end of the needle pointing

north is called the *austral* or *southern* pole, and that pointing to the south the *boreal* or *northern* pole—a designation based on this hypothesis of a terrestrial magnet, and on the law that unlike magnetisms attract each other. In practice it will be found more convenient to use the English names, and call that end of the magnet which *points* to the north the north seeking or north pole, and that which points to the south the south seeking or south pole. That end of the needle which points to the north is often provided with a small transverse mark, and the end is accordingly spoken of as the *marked end.*

405. **Magnetic meridian. Declination.**—When a magnetic needle points towards the north, if we conceive a plane *ab* passing through its two poles, NS, this plane is what is called the *magnetic meridian* of the place. The direction of this plane does not in general coincide with the geographical meridian of the place, which is the imaginary plane *ns* passing through this place and through the earth's poles. The angle (fig. 371) which the direction *ab* of the magnetic needle NS makes with the geographical meridian *ns* is by some called the *declination* of the place, and by others, and more especially in the navy, the *variation*. In other words, as the magnet needle does not exactly point to the earth's north, the declination is the difference between this direction and the true north. Sometimes the north pole of the needle is to the west of the meridian, and sometimes it is to the east. In the former case the declination is said to be *easterly*, and in the latter case *westerly*.

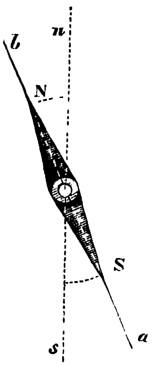


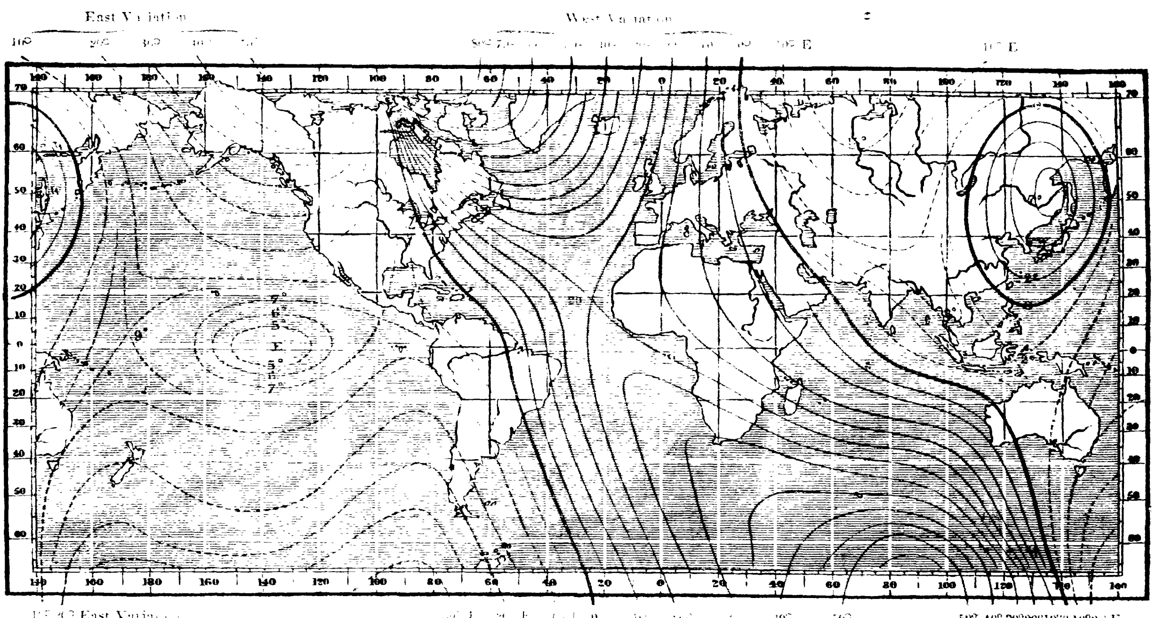
Fig. 371.

The declination of the magnetic needle, which varies in different places, is at present west in Europe and in Africa, but east in Asia and in North and South America. It shows, further, considerable variations even in one and the same place.

Thus at London the needle showed in 1580 an east declination of 11° 36′; in 1663 it was at zero; from that time it gradually tended towards its west, reaching the maximum declination of 24° 41′ in 1818; since then it has steadily diminished; it was 22° 30′ in 1850, and is now (1887) 17° 48′ W.

At Yarmouth and Dover the variation is about 40′ less than at London; at Hull and Southampton about 20′ greater; at Newcastle and Swansea about 1° 15′, and at Liverpool 1° 30′, at Edinburgh

LINES OF EQUAL MAGNETIC VARIATION, 1882



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2° 5′, and at Glasgow and Dublin about 2° 25′ greater than at London.

Isogonic lines are lines connecting those places on the earth's surface in which the declination is the same. Maps on which such isogonic lines are depicted are called *declination* or *variation maps*; and a comparison of these in various years is well fitted to show the variation which this magnetic element undergoes. The opposite plate represents a map in Mercator's projection giving these lines for the year 1882. It will be seen that the surface of the globe is divided by these lines into two regions: one, the smaller, in which the variation is westerly, as indicated by the continuous lines; the other in which the variation is easterly, as indicated by

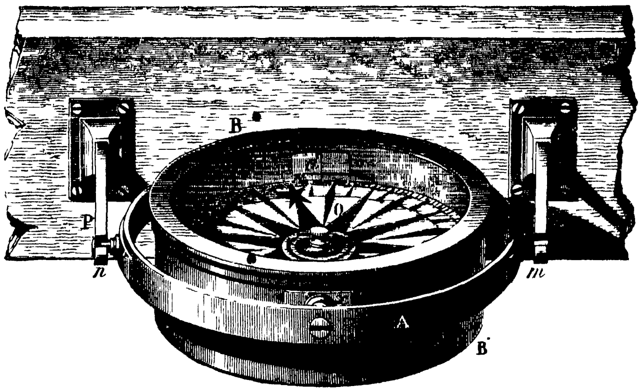


Fig. 372.

the dotted lines. This chart is useful to the mariner as not only giving him the declination in any place, but also as showing him those regions on the globe where the declination changes most rapidly. Of these the most remarkable are the coast of Newfoundland, the Gulf of St. Lawrence, the seaboard of North America, and the English Channel and its approaches.

Besides these variations, which are called *secular variations*, the declination of the magnetic needle undergoes accidental variations known as *perturbations* or *magnetic storms*; these are manifested during the occurrence of thunder-storms, of volcanic eruptions, and during the appearance of aurora borealis. The effect of the aurora is felt at great distances. Auroras which are only

visible in the north of Europe act on the needle even in these latitudes. In polar regions the needle frequently oscillates several degrees ; its irregularity on the day before the aurora borealis is a forecast of the occurrence of this phenomenon.

406. **Mariner's compass.**—The most important application of the magnetic action of the earth is in the *mariner's compass.* This is a declination compass used in guiding the course of a ship. Fig. 372 represents a view of the whole, and fig. 373 a vertical section. It consists of a cylindrical case BB′, which, to keep the compass in a horizontal position in spite of the rolling of the vessel, is supported on *gimbals.* These are two concentric rings, one of which, attached to the case itself, moves about the axis *xd* which plays in the outer ring AB, and this moves in the supports PQ, about the axis *mn*, at right angles to the first.

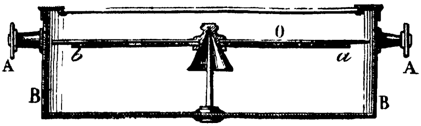


Fig. 373.

In the bottom of the box is a pivot, on which is placed, by means of an agate cap, a magnetic bar, *ab*, which is the needle of the compass. On this is fixed a disc of mica, a little larger than the length of the needle, on which is traced a star or *rose*, with thirty-two branches, making the eight points or *rhumbs* of the wind, the demi-rhumbs, and the quarters. The branch ending in a small star, and called N, corresponds to the bar *ab*, which is underneath the disc.

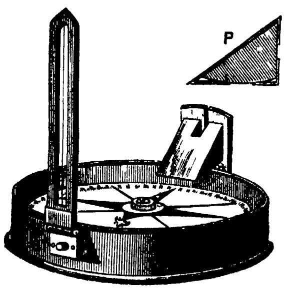


Fig. 374.

The compass is placed near the stern of the vessel in the *binnacle.* Knowing the direction of the compass in which the ship is to be steered, the pilot has the rudder turned till the direction coincides with the sight vane, passing through a line *d* marked on the inside of the box, and parallel with the keel of the vessel.

406*a*. **Prismatic compass.**—The *prismatic compass* is used in surveying ; it differs from the mariner's compass mainly in its dimensions, and in the way in which observations are made. It

consists of a shallow metal box about 2½ inches in diameter (fig. 374); the needle, which is fixed below the compass card, plays on a pivot. A metal frame, across which is stretched a horse-hair, forms a sight vane. Exactly opposite this is a right-angled prism, P, enclosed in a metal case with an eyehole and a slit as represented at the side.

In order to make an observation the compass is held horizontally, and so that the slit in the prism, the hair of the sight vane, and the distant object are seen to be in the same line; looking through the eyehole, the angle which the needle makes is then noted; a similar observation is made with another object, and thus the angle between them or their *bearing* is given. The sight vane is connected with a lever, and can be turned down when it presses the magnet on the pivot, thus keeping it rigid, so that the compass can be transported in any position.

As the image is seen through the convex face of the prism it is magnified, and as it is seen by reflection it is reversed, so that in order to read the figures correctly they must be reversed on the card.

407. **Inclination compass.**—When a steel needle supported on a vertical pivot, as represented in fig. 375, has been so accurately balanced that it is quite horizontal *before magnetisation*, it is observed that when it is magnetised it ceases to retain its horizontal position, and the north pole dips downward. When this phenomenon was first observed, it was ascribed to a defect of construction, but the regularity with which it occurred proved that it must be ascribed to the directive action of the earth.

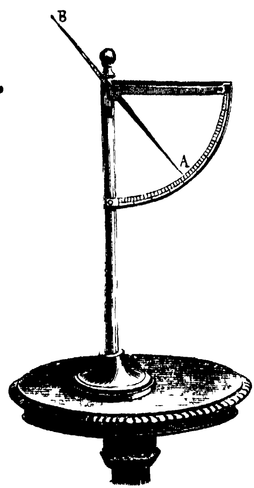


Fig. 375.

In order to observe this phenomenon, the mode of suspension is modified, and the needle is fixed to a horizontal axis so that it can move in a vertical plane as represented in fig. 375. The angle it forms is read off on the divided circle.

Thus arranged, the apparatus is called the *inclination compass* or *dipping needle*, and the angle which the needle makes with the horizon when it is placed so that its plane of oscillation

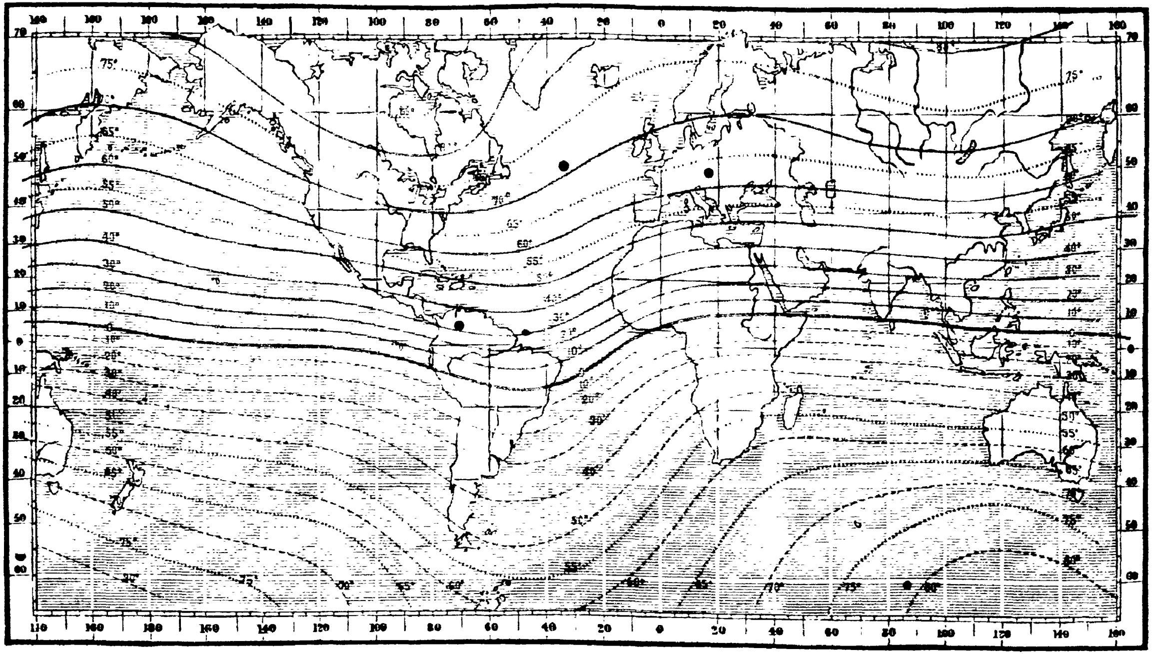
is in the magnetic meridian, is called the ***magnetic inclination*** or ***dip***.

The value of the dip, like that of the declination, differs in different localities. It is greatest in the polar regions, and decreases with the latitude towards the equator, where there are a series of points at which it is zero; that is, at which the needle is horizontal. The line joining these parts is called the terrestrial *magnetic equator*. In London at the present time (1887) the dip is 67° 32′, reckoning from the horizontal line. In the southern hemisphere the inclination is again seen, but in a contrary direction; that is, the south pole of the needle dips below the horizontal line.

The terrestrial *magnetic poles* are those places in which the dipping needle stands vertical; that is, where the inclination is 90°. In 1830 the first of these, the terrestrial north pole, was found by Sir James Ross, in 96° 43′ west longitude and 70° north latitude. The same observer found in the South Sea, in 76° south latitude and 168° east longitude, that the inclination was 88° 37′. From this and other observations it has been calculated that the position of the magnetic south pole was at that time in about 154° east longitude and 75½° south latitude.

Lines connecting places on the earth's surface at which the dipping needle makes equal angles are called *isoclinic lines*. They have a certain analogy and parallelism with the parallels of latitude (40), and the term *magnetic latitude* is sometimes used to denote positions on the earth with reference to the magnetic dip. The plate facing this page is an inclination map for the year 1882, the construction of which is quite analogous to that of the map of declination.

The inclination is subject to secular variations, like the declination. At Paris, in 1671, the inclination was 75°: since then it has been continually decreasing, and in 1859 was 66° 14.′ In London also the dip has continually diminished since 1720 by about 2·6′ per annum. In 1821 it was 70° 3′; in 1838, 69° 17′; in 1854 it was 68° 31′; in 1859 it was 68° 21′; it is now (1887) 67° 25′. It is also subject to slight annual and diurnal variations; being, according to Hansteen, about 15′ greater in summer than in winter, and 4′ or 5′ greater before noon than after.



To face p. 460.

CHAPTER III.

METHODS OF MAGNETISATION.

408. **Magnetisation by the influence of the earth.**—To *magnetise a substance* is to impart to it the properties of attracting particles of iron, and of turning towards the north when suitably suspended. Magnetisation can be produced slowly by the influence of the earth, or more rapidly by rubbing with a magnet; or by means of electricity. The best material for permanent magnets is steel. There is considerable difference in different specimens of iron as regards their power of accepting and retaining magnetisation.

The magnetic action of the globe is powerful enough to act as a source of magnetisation. This may be illustrated by taking a rod of wrought iron, and placing it in the magnetic meridian, so that it makes an angle with the horizontal equal to the angle of dip. In this position the earth's magnetism, acting by induction on the rod, converts the lower end into a north pole, and the upper into a south pole. Yet this magnetisation is not permanent, for, if the rod be turned upside down, the poles are inverted, since pure soft iron is destitute of coercive force. But if, while the rod is in the above position, it be hammered, or twisted, the hammering or the twisting imparts to it a certain amount of coercive force, and it retains for some time the magnetisation thus evoked. If several thin rods thus magnetised are united so that poles of the same name are together, a tolerably powerful magnet is obtained.

It is this magnetising action of the earth which develops the magnetism frequently observed in steel and iron objects, such as fire-irons, gas and water pipes, railings, gates, lightning conductors, stove pipes, lamp-posts, etc., which remain for some time in a more or less inclined position. They become magnetised with the north pole downwards, just as if placed over the south pole of a powerful magnet. The magnetism of native oxide of iron has doubtless been produced by the same causes; the very different magnetic

power of different specimens being partly attributable to the different position of the veins of ore with regard to the line of dip. The ordinary irons of commerce are not quite pure, and possess a feeble coercive force; hence a feeble magnetic polarity is generally found to be possessed by the tools in a smith's shop. Cast iron, too, has usually a great coercive force, and can be permanently magnetised.

The turnings, also, of wrought iron and of steel produced by the powerful lathes of our ironworks are found to be magnetised. So too are rifles which have been stacked in a vertical position.

Magnetisation by magnets. In magnetising bar magnets, and especially magnetic needles, the method generally adopted is to

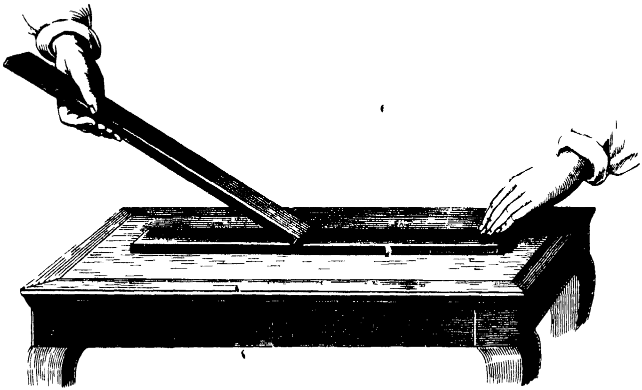


Fig 376

rub them with powerful magnets. The principle is applied in the methods of what are called *single*, *separate*, and *double touch*.

The method of single touch (fig. 376) consists in moving one pole of the powerful magnet from one end to the other of the bar to be magnetised, and repeating this operation several times, always in the same direction. The neutral magnetism is thus gradually decomposed throughout all the length of the bar, and that end of the bar which was touched last by the magnet is of opposite polarity to the end of the magnet by which it has been touched. This method only produces a feeble magnetic power, and is accordingly, only used for small magnets. It has, further, the disadvantage of frequently developing intermediate poles (399).

In the method of separate touch the steel bar is rubbed separately with the contrary poles of two magnets, proceeding in opposite directions from the centre towards the ends.

Magnetisation by double touch. In this method the two magnets are placed with their poles opposite each other in the middle of the bar to be magnetised. But, instead of moving them in opposite directions towards the two ends, as in the method of separate touch, they are kept at a fixed distance by means of a piece of wood placed between them (fig. 377), and are simultaneously moved first towards one end, and then from this to the other end, repeating this operation several times, and finishing in the middle, taking care that each half of the bar receives the same number of frictions.

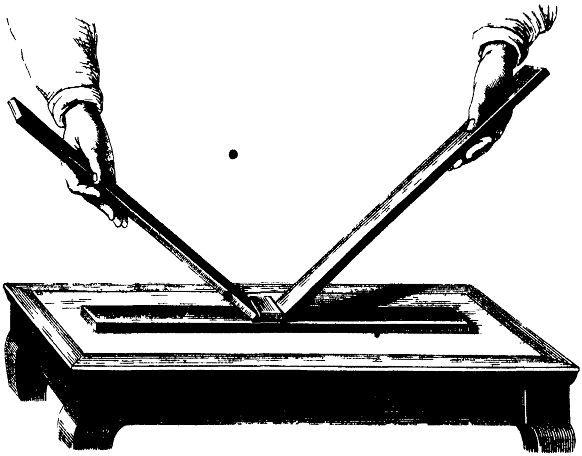


Fig. 377.

Magnetisation by means of electrical currents (497) is the most powerful means of imparting magnetic properties, and is the one generally used for large magnets, whether bar or horse-shoe. Whatever be the mode of magnetisation, there is for each particular magnet a maximum of strength which cannot be exceeded. When this is attained the magnet is said to be *saturated.*

409. **Magnetic batteries. Armatures.**—Magnetic *battery*, or *magazine*, is the name given to a system of bars joined with their

similar poles together. Sometimes the bars are straight, as represented in figs. 367 and 368, and sometimes they are curved, as in fig. 378, which represents a horse-shoe battery. Very powerful compound magnets are now made by separately magnetising a number of thin steel plates and then joining them. The magnetic power of such a system is not quite equal to that of the sum of the strengths of all the separate magnets, but it is considerably greater than that of a solid magnet of the same weight.

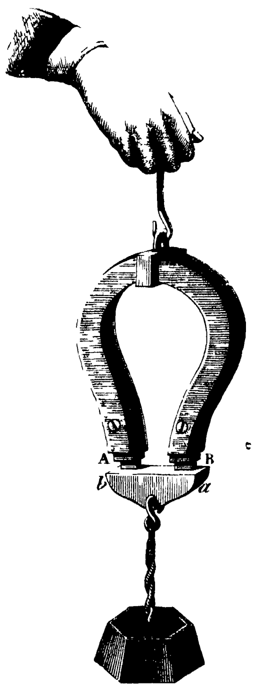


Fig. 378.

Magnets, whether natural or artificial, would soon lose their power if they were left to themselves, and they must therefore be provided with *armatures*. These names are given to pieces of soft iron which are placed in contact with the poles, such as the piece, *ab*, in fig. 378. The two poles of the magnet acting inductively on this piece produce in it a north pole at *a*, and a south pole at *b*, and these two poles thus produced react in turn upon the magnetised bar, and by preventing the recomposition of its two fluids cause it to retain its force. The piece, *ab*, is also called the *keeper*; to it is suspended the weights which the magnet is intended to support.

This suggests a method of determining the strength of horse-shoe magnets. If a scale pan be attached to the keeper, and weights be gradually added, the keeper will ultimately become detached; the greatest weight which such a magnet will just support measures, what is called its *portative force*. Magnets such as are used in the telephone are constructed which will support from 15 now to 25 times their own weight.

The strength of bar magnets is best measured by the varying extents to which they deflect a magnetic needle. The bar magnet is placed at right angles to the magnetic meridian at some distance from the needle, and so that the prolongation of the axis of the bar magnet cuts the needle. The magnet to be compared is now

placed in the same position on the other side of the needle, the same poles facing each other. By bringing the second magnet nearer or further away from the needle, the needle will not be deflected at a certain distance ; the action of each magnet on the needle is then the same. If, now, the respective distances of the acting poles of the two magnets be measured, the strengths of the two magnets are as the *cubes* of their distances. Thus, if the distance of the magnet A is 6 inches and that of the magnet B 7 inches, then the strength of A is to that of B as 216 to 343, or nearly as 12 is to 17.

Ordinary compass needles, such as are used in surveying, are not provided with a keeper. They should, when not in use, be left unclamped. Being then free to oscillate, they set in the magnetic meridian, and the earth's magnetism thus acts as a keeper.

409*a*. **Magnetism of iron ships.**—The inductive action of terrestrial magnetism upon the masses of iron always found in ships exerts a disturbing action upon the compass needle. The *deviation* of the compass due to this *local attraction*, as it is called, may be so considerable as to render the indications of the needle almost useless if it be not guarded against. A full account of the manner in which local attraction is produced, and in which it is compensated, is inconsistent with the limits of this book, but the most important points are the following :—

i. A vertical mass of soft iron in the vessel, say in the bows, would become magnetised under the influence of the earth ; in the northern hemisphere, the lower end would be a north pole, and the upper end a south pole ; and as the latter may be assumed to be nearer the north pole of the compass needle, it would act upon it. So long as the vessel was sailing in the magnetic meridian this would have no effect ; but in any other direction the needle would be drawn out of the magnetic meridian, and a little consideration will show that when the ship was at right angles to the magnetic meridian the effect would be greatest. This *vertical induction* would disappear twice in swinging the ship round, and would be at its maximum twice ; hence the deviation due to this cause is known as *semicircular deviation*.

ii. Horizontal masses again, such as deck-beams, are also acted upon inductively by the earth's magnetism, and their induced magnetism exerts a disturbing influence upon the magnetic needle. The effect of this horizontal induction will disappear when the ship is in the magnetic meridian, and also when it is at right angles thereto. In positions intermediate to the above the disturbing

influence will attain its maximum. Hence in swinging a ship round there would be four positions of the ship's head in which the influence would be at a maximum, and four in which it would be at a minimum. The effect of horizontal induction is accordingly spoken of as *quadrantal deviation.*

iii. *Heeling error.* The effect of iron beams on a compass when a vessel *heels over* under the influence of wind or sea is to cause a deviation proportional to the amount of heeling.

The maximum deviation when heeling is when the ship's head is north or south by the compass, and it vanishes when the ship's head is east or west.

iv. In the process of building an iron ship the hammering and other mechanical operations will cause it to become to a certain extent magnetised. The distribution and the axis of magnetism depend on the position in which the ship has been built. This magnetism is mostly fugitive and disappears to a great extent after a ship has been at sea some while, the buffeting of the waves assisting in its dispersion ; this may be called *subpermanent,* while there remains a part called *permanent* magnetism.

The influence of these various causes may be ascertained by the process of 'swinging ship.' This consists in comparing the indications of the ship's compass with those of a standard compass on shore. The ship is then hauled round with her head to the various points of the compass, and the readings of the compass in the various positions are compared.

From this comparison a table of *deviations* is compiled showing the reading of the ship's compass for every point of the true compass. One school of navigators content themselves with steering by the use of this table, others prefer to correct their compass by compensating the action of the iron of their vessel by magnets and masses of soft iron in the manner now briefly described.

The *semicircular deviation* which is chiefly caused by the permanent magnetism is corrected by a magnet placed parallel to the line of its semicircular deviation under the needle.

The *quadrantal deviation* caused by the iron beams is corrected by hollow cast-iron globes placed on a level with the compass needle.

The *heeling error* is corrected by a magnet placed in a vertical position under the compass card.

BOOK VIII.

FRICTIONAL ELECTRICITY.

CHAPTER I.

FUNDAMENTAL PRINCIPLES.

410. **Electricity.**—Electricity is a powerful physical agent which manifests itself mainly by attractions and repulsions, but also by luminous and heating effects, by violent shocks, by chemical decomposition, and many other phenomena. Unlike gravity, it is not inherent in bodies, but is evoked in them by a variety of causes, among which are friction, pressure, chemical action, heat, and magnetism.

Thales, one of the Greek sages, 600 B.C., knew that when *amber* was rubbed with silk it acquired the property of attracting light bodies, such as feathers, pieces of straw, etc., and from the Greek form of this word (ἤλεκτρον, *electron*) the term *electricity* has been derived. Six centuries after it was found, Pliny, the celebrated Roman naturalist, writes: 'When the friction of the fingers has imparted to it heat and life, it attracts pieces of straw as a magnet attracts particles of iron.' This is nearly all the knowledge left by the ancients; it was not until towards the end of the sixteenth century that Dr. Gilbert, physician to Queen Elizabeth, called attention to this property of amber, and showed that it was not limited to amber, but that other bodies, such as sulphur, wax, glass, etc., also acquired the property of attracting light bodies when they are rubbed or struck with flannel or with cat-skin.

To repeat this experiment, a glass rod, or a stick of sealing-wax or shellac, is held in the hand, and rubbed with a piece of flannel, or with the skin of a cat; it is then found that the parts rubbed have the property of attracting light bodies, such as pieces of silk, wool, feathers, paper, bran, gold leaf, etc., which, after remaining a short

time in contact, are again repelled (fig. 379). Not only have the substances thus rubbed the property of attracting light particles, but they also become luminous in the dark; they give sparks, and present a number of phenomena, the cause of which is described under the general term *electricity*, and the derivation of which has already been given.

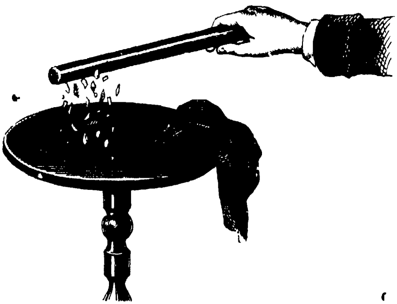


Fig. 379.

However slow may have been the progress of the science of electricity in ancient times and in the Middle Ages, its progress during the eighteenth and nineteenth centuries has been extremely rapid. In the last seventy or eighty years, more especially, the new facts discovered have been so numerous and remarkable, and their applications so curious and important, that electricity has been compared to a kind of fairy, of whom it was only necessary to ask miracles to have them realised.

411. **Sources of electricity.**—The causes which develop electricity are numerous; they may be divided into mechanical, physical, and chemical sources.

The *mechanical sources* are, besides friction, fracture, pressure, and cleavage. Thus, when a piece of sugar is broken in the dark, a feeble luminosity is seen, due to the electricity produced. If a piece of Iceland spar be pressed against an orange, and then quickly removed, it will be found to be electrified. Cleavage is also a source of electricity; if a plate of mica be rapidly split in the dark, a faint phosphorescent light is perceived on the separated surfaces.

The *physical sources* are variations in temperature; these effects are observed in some minerals, and more especially in tourmaline, which exhibits electrical properties when either heated or cooled.

If some melted sulphur be poured into a wineglass which has been previously warmed, and a glass rod be held in the fused mass, when it solidifies this serves as a handle to lift it out, and the sulphur will be found to be strongly electrified.

Lastly, the *chemical sources* are the combinations and the de-

compositions of bodies. Thus, most metals, like zinc, iron, copper, when placed in an acid, are dissolved, and unite with the acid to form salts. Now during these combinations considerable quantities of electricity are developed. The same is the case with chemical decomposition ; that is, when compound bodies are separated into their elements.

The most powerful sources of electricity are friction and chemical action. We shall first of all study the influence of the first cause, and shall subsequently investigate the latter under the name of VOLTAIC ELECTRICITY.

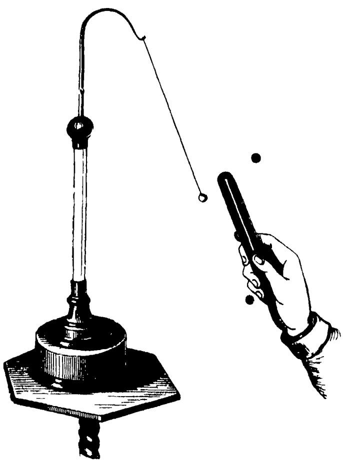


Fig. 380.

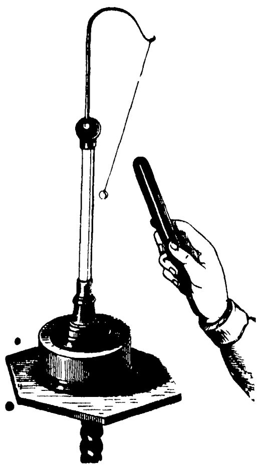


Fig. 381.

412. **Electroscopes: Electrical pendulum.**—In order to ascertain whether bodies are electrified or not, instruments called *electroscopes* are used. The simplest of these, the *electric pendulum* (fig. 380), consists of a small pith ball attached by means of a silk thread to a brass rod resting on a glass support. To find whether a body is electrified or not, it need only be presented to an electrical pendulum ; in the first case there is attraction, while in the second case there is not. Yet the electrical pendulum would not be affected by a body very feebly charged with electricity. More complicated and more delicate apparatus must then be had recourse to, which will be described afterwards (426, 432).

413. **Distinction of the two kinds of electricity.**—If electricity be developed on a glass rod by friction with silk, and the rod be brought near an electrical pendulum (fig. 380), the ball will be attracted to the glass, and after momentary contact will be again repelled. By this contact the ball becomes electrified, and so long as the two bodies retain their electricity repulsion follows when they are brought near each other. If a stick of sealing-wax, electrified by friction with flannel or skin, be approached to another electrical pendulum, the same effects will be produced, the ball will fly towards the wax, and after contact will be repelled. Two bodies which have been charged with the same electricity repel one another. But the electricities, respectively developed in the preceding cases, are not the same. If, after the pith ball has been touched with an electrified glass rod, an electrified stick of sealing-wax, and then an electrified glass rod, be alternately approached to it, the pith ball will be *attracted* by the former and *repelled* by the latter. Similarly if the pendulum be charged by contact with electrified sealing-wax, it will be *repelled* when this is approached to it, but *attracted* by the approach of the electrically excited glass rod (fig. 381).

This distinction may be conveniently shown by means of two discs, one of glass fixed to an insulated handle of glass, and the

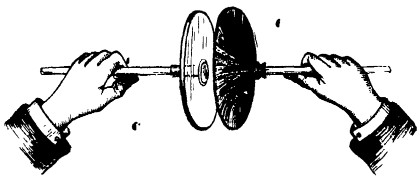


Fig. 382.

other of wood covered with leather or flannel (fig. 382) similarly fixed; if these are rubbed together, and then presented separately to an electrified pith ball, the ball will be attracted by the one disc and repelled by the other.

On experiments of this nature, Dufay first made the observation that there are two different electricities; the one developed by the friction of glass, the other by the friction of resin or shellac. To the first the name *vitreous* electricity is given; to the second the name *resinous* electricity.

414. **Hypothesis of two electrical fluids.**—Notwithstanding the great importance and interest of the numerous electrical phenomena, we are still ignorant of their real cause. Various

hypotheses have been made to account for them. The most convenient, perhaps, is that which was propounded by Symmer, an English physicist.

Symmer's theory assumes that every body contains an indefinite quantity of a subtile imponderable matter, which is called the *electrical fluid*. This fluid is formed by the union of two fluids—the *positive* and the *negative*. When they are combined they neutralise one another, and the body is then in the natural or neutral state. By friction, by chemical action, and by several other means, this neutral fluid may be decomposed and the two fluids separated, but one of them can never be excited without a simultaneous and equal production of the other. There may, however, be a greater or less excess of the one or the other in any body, and it is then said to be electrified *positively* or *negatively*. The two electricities were formerly called *vitreous* and *resinous*, but these have given place to the terms *positive* and *negative* electricities, to which they respectively correspond, and which were first used by Franklin. This distinction is merely conventional; it is adopted for the sake of convenience, and there is no other reason why resinous electricity should not be called positive electricity.

Electricities of the same kind repel one another, and electricities of opposite kinds attract each other. The electricities can circulate freely on the surface of certain bodies, which are called *conductors*, but remain confined to certain parts of others, which are called *nonconductors* (417).

As has been already said, this theory is quite hypothetical; but its general adoption is provisionally justified by the convenient explanation which it gives of electrical phenomena.

415. **Laws of electrical attraction and repulsion.**—Adopting this two-fluid theory, the qualitative and quantitative laws of electrical attraction and repulsion may be stated as follows:—

I. *Two bodies charged with the same electricity repel each other; two bodies charged with opposite electricities attract each other.*

II. *The repulsions or attractions between two electrified bodies are in the inverse ratio of the square of their distances.* That is to say, that if two bodies be charged to a certain extent with electricity, they will attract or repel each other with a certain force according as the electricities are different or are the same; if now the distance between them be increased to twice or thrice the original amount, the attraction or repulsion will be one-fourth or one-ninth of what it was originally.

III. *The distance remaining the same, the force of attraction or repulsion between two electrified bodies is directly as the product of the quantities of electricity with which they are charged.* Thus if the quantity of electricity with which a body is charged be twice or thrice its original amount, it will have twice or three times the attractive or repulsive force.

The first of these laws follows from the experiment described above (413); the second and third were first stated by Coulomb, and may be demonstrated by an apparatus which he devised, which is known as *Coulomb's balance.*

416. **Coulomb's balance.**—Represented in fig. 383, this apparatus consists of a glass cylinder closed at the top by a plate of the same material. In this is an aperture on which is a glass tube, *d.* This is not rigidly fixed, but can be turned round. At the top of this tube is a brass cap, consisting of two pieces—one *b*, which is rigidly fixed to the tube, *d*, and the other fitting in the first like a socket, so that it can be turned by the button, *t.* On *k* is a scale *e*, graduated in 360 degrees, and turning with it; *b* is provided with a fixed index, *a*, which shows by how many degrees the disc is turned.

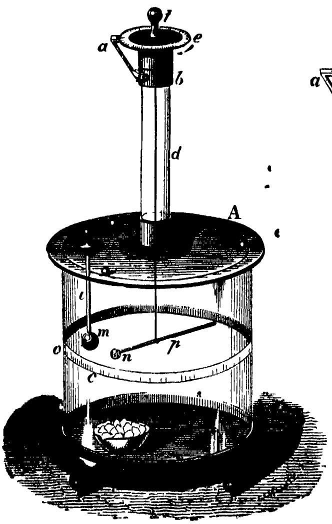


Fig. 383.

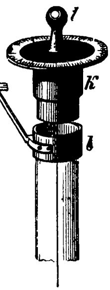


Fig 384.

To the disc is fixed a very fine silver wire, to which is suspended a horizontal shellac thread, *p*, terminated at one end by a small disc of thin metal foil, *n.* In the cover, A, near the edge, is a second aperture through which can be passed a glass rod, *i*, with a wooden handle, *r*, at one end, and terminating in a brass ball, *m.* A scale of 360 degrees is fixed on the cage, opposite the zero of which is the ball, *m.*

In experimenting with this apparatus the air is dried by placing in the cage some chloride of calcium, which is a highly hygroscopic substance. To establish the second law, that electrical attractions vary inversely as the square of the distance, the disc, *e*, is first turned until its zero corresponds to the mark, *a*; the tube, *d*, and the whole cap, *k*, is slowly turned, until, the silver thread being destitute of torsion, and the needle, *p*, at rest, the latter corresponds to the zero of the graduated circle; the knob, *m*, is in the same position, and thus presses against *n*. The knob, *m*, is then removed and electrified, and replaced in the apparatus, through the aperture, *r*. As soon as the electrified knob, *m*, touches *n*, the latter becomes electrified, and is repelled, and after a few oscillations comes to rest, at ten degrees, for instance; the resistance of the wire to further torsion then just balances the force of repulsion. As the arc of ten degrees is virtually the same as its chord, the number ten may be regarded as representing the distance of *m* and *n*. If the cap, *e*, is turned from left to right in the figure, it is found that, to reduce the distance to five degrees, it must be turned through thirty-five degrees. The wire is thus twisted through thirty-five degrees at the top and through five at the bottom: its total torsion is forty degrees; that is to say, four times as much as it was at first. Hence at the distance five the repulsion is four times as great as at the distance ten; for it is a known law, that the angle of torsion is proportional to the force of torsion. It may be shown in the same manner that, to make the distance from *m* to *n* one-third what it was, the total torsion must be ninety degrees—that is, nine times as great; the second law is thus thereby proved.

In order to prove that attractions and repulsions between electrified bodies are proportional to the quantities of electricity which each of them possesses, the ball, *m*, is again electrified and placed in the cage; after contact it repels the disc, *n*, through a distance of, let us say, twelve degrees. The ball, *m*, is now withdrawn and placed in contact with a second brass ball of the same diameter, but insulated and unelectrified. As the electricity is equally distributed over both balls, the ball, *m*, loses half its electricity, and on again placing it in the cage, the repulsion which was twelve degrees is now only six, thereby verifying the third law.

417. **Conductors and nonconductors.**—When a glass rod, rubbed at one end, is brought near an electroscope, that part only will be found to be electrified which has been rubbed; the other end will produce neither attraction nor repulsion. The same is the

case with a rod of shellac or of sealing-wax. In these bodies electricity does not pass from one part to another—they do not *conduct* electricity. Experiment shows that when a metal has received electricity in any of its parts, the electricity instantly spreads throughout its entire surface. Metals are hence said to be good *conductors* of electricity.

Bodies have, accordingly, been divided into *conductors* and *nonconductors.* This distinction is not absolute, and we may advantageously consider all bodies as offering a certain *resistance* to the passage of electricity which varies with the nature of the substance. Those bodies which offer little resistance are conductors, and those which offer great resistance are nonconductors or *insulators* ; electrical *conductivity* is thus the inverse of electrical *resistance.* We are to consider that between conductors and nonconductors there is a *quantitative* and not a *qualitative* difference ; there is no conductor so good but that it offers some resistance to the passage of electricity, nor is there any substance which insulates so completely but that it allows some electricity to pass. The transmission from conductors to nonconductors is gradual, and no sharp line of demarcation can be drawn between them.

In this sense we must understand the following table, in which bodies are classed as *conductors*, *semiconductors*, and *nonconductors* ; those bodies being conveniently designated as conductors which, being held in the hand, and applied to an electroscope charged with either kind of electricity, discharge it almost instantaneously ; semiconductors being those which discharge it in a short but measurable time—a few seconds, for instance ; while nonconductors effect no perceptible discharge, even in the course of a minute.

Conductors.	*Semiconductors.*	*Nonconductors.*
Metals.	Alcohol and ether.	Dry oxides.
Graphite.	Powdered glass.	Air and dry gases.
Acids.	Dry wood.	Dry paper.
Water.		Silk.
Snow.		Diamond and precious stones.
Vegetables.		Caoutchouc.
Animals.		Glass.
		Sulphur.
		Resins.

418. **Insulating bodies. Common reservoir. Electrification of conductors.**—Bad conductors are called *insulators*, for they are

used as supports for bodies in which electricity is to be retained. A conductor remains electrified only so long as it is surrounded by insulators. If this were not the case, as soon as the electrified body came in contact with the earth, which is a good conductor, the electricity would pass into the earth, and diffuse itself through its whole extent. On this account, the earth has been named the *common reservoir.* A body is insulated by being placed on a support with glass feet, or on a cake of resin or gutta-percha, or by being suspended by silk threads. No bodies, however, insulate perfectly; all electrified bodies lose their electricity more or less rapidly by means of the supports on which they rest. Glass is in itself a very perfect insulator, but it is always somewhat hygroscopic, and the aqueous vapour which condenses on it affords a passage for the electricity: the insulating power of glass is materially improved by coating it with shellac or copal varnish. Dry air is a good insulator; but, when the air contains moisture, it condenses on the supports of the electrified body and conducts electricity, and this appears to be the principal source of the loss of electricity.

It is owing to their great conductivity, that metals do not become electrified by friction when held in the hand. But if they are insulated, and then rubbed, they give good indications. This may be seen by the following experiment:—A brass tube is provided with a glass handle by which it is held, and it is then rubbed with dry silk or flannel. On approaching the metal to the electrical pendulum (fig. 380), the pith ball will be attracted. If the metal is held in the hand electricity is indeed produced by friction, but it immediately passes through the body into the ground.

The experiment may also be conveniently made with the insulated brass sphere represented in fig. 386. If this is held by the stem, and the sphere is flapped with a dry silk handkerchief, it becomes strongly electrified.

Electrifying by contact is due to conductivity. For when an insulated conductor in the neutral state is made to touch an electrified conductor, a portion of the latter passes instantaneously to the former. If the two bodies have the same surface, and the same shape—for instance, two spheres of the same diameter—the electricity is equally distributed on the two; but if the bodies differ in shape or surface the electricity in unequally distributed.

419. **Law of the development of electricity by friction.**—Whenever two bodies are rubbed together, the two electricities are developed at the same time and in equal quantities—one body

takes the positive, and the other negative electricity. This may be best proved by the following simple experiment devised by Faraday :—A small flannel cap provided with a silk thread is fitted on the end of a stout rod of sealing-wax (fig. 385), and rubbed round a few times. When the cap is removed by means of a silk thread, and presented to a pith ball pendulum charged with positive electricity, the latter will be repelled, proving that the flannel is charged with positive electricity; while, if the shellac is presented to the pith ball, it will be attracted, showing that the shellac is charged with negative electricity. Both electricities are present in equal quantities; for if the rod be presented to the electroscope before removing the cap, no action is observed.

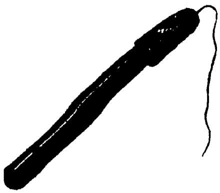


Fig. 385

The kind of electricity developed on any particular body by friction depends on the body by which it is rubbed. Thus glass becomes negatively electrified when rubbed with catskin, but positively when rubbed with silk. So, too, sulphur when rubbed with the hand becomes negatively or resinously electrified, but rubbed with gun-cotton it is positively or vitreously electrified. In the following list, which is called the *electrical series*, the substances are arranged in such an order, that each becomes positively electrified when rubbed with any of the bodies following, but negatively when rubbed with any of those which precede it :—

1. Catskin.	5. The hand.	9. Resin.
2. Flannel.	6. Wood.	10. Sulphur.
3. Glass.	7. Metals.	11. Gutta-percha.
4. Silk.	8. Caoutchouc.	12. Gun-cotton.

420. **Distribution of electricity on the surface of bodies.**—Numerous experiments show that when a body is electrified, all the electricity goes to the surface, where it is accumulated as an extremely thin layer, tending constantly to escape, and flying off in short, when it is not retained by any obstacle. This may be demonstrated by the following experiment, which is due to Biot.

A hollow brass globe, fixed to an insulating support, is provided with two brass hemispherical envelopes which fit closely, and can be separated by glass handles. The interior is now electrified, and the two hemispheres are brought in contact with each other and with the sphere. On then rapidly removing them (fig. 386), the

coverings will be found to be electrified, while the sphere is in its natural condition, and indicates no electricity. Thus in removing, so to say, the surface of a body, all the free electricity it contained is also removed, which shows clearly that the electricity is on the surface. That electricity resides solely on the surface is further proved by the fact that two metal spheres of the same diameter, but one of them solid and the other hollow, take the same charge of electricity when applied to the same constant source of electricity,

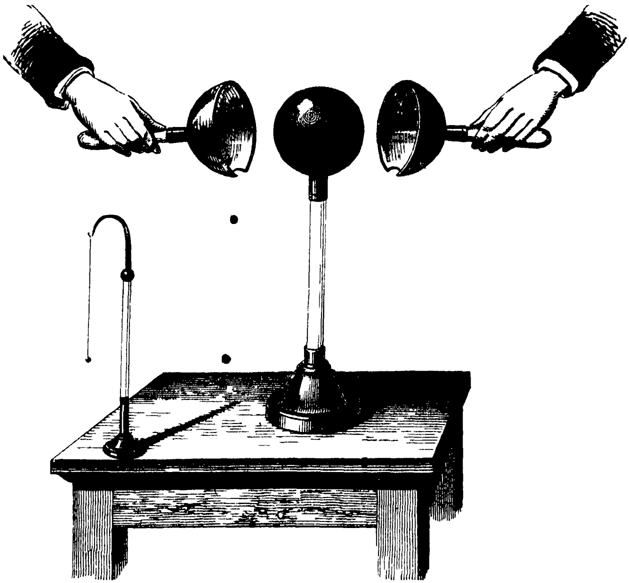


Fig 386

for instance, the prime conductor of an electrical machine (423) in full activity. This is proved by placing them successively at the same distance from a gold-leaf electroscope (426). It is thus found that each produces the same amount of divergence in the leaves.

The same point may also be illustrated by means of the following apparatus (fig. 387). Two tinplate rings, *e*, about eight to ten inches in diameter, are connected by four thin vertical tinplate bands, *a*, *b*, *c*, *d*, and by twenty-four vertical wires, with each other; with the exception of two, the latter are not shown so that the interior of

the apparatus may be seen. To each of the vertical bands a strip of paper is fastened both inside and out, and a similar pair of strips is suspended to a cross bar. If this apparatus is insulated and connected with an electrical machine at work, the outer paper strips are repelled, while those in the interior show no signs of electrical repulsion.

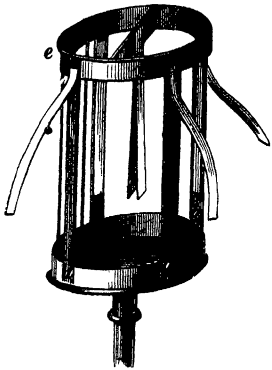


Fig. 387.

Franklin placed a long chain in a metal teapot, to the spout of which were suspended two pith balls. The teapot was insulated and electrified. On drawing out the chain by a silk string he found that the divergence of the pith balls diminished, but was restored to its original amount when the chain was brought back. Here then was no alteration in the mass of metal concerned in the experiment, but there was in the extent of surface.

One of the most remarkable illustrations of the distribution of electricity on the surface is that of Faraday, who framed a large cube of wood, 12 feet in the side, and covered it with sheet lead so that a conducting surface was formed. This was insulated from the ground, and connected with a powerful electrical machine in full work. 'I went into the cube,' said Faraday, 'and lived in it, but though I used lighted candles, electrometers, and all other tests of electrical states, I could not find the least influence upon them, or indication of anything particular given by them, though all the time the outside of the cube was powerfully charged, and large sparks and brushes were starting from every part of its outer surface.'

This property of electricity of residing on the surface is applied in *electrical screens*. If it be desired to protect anything, such as a delicate gold-leaf electroscope, from accidental injury from a discharge, it is sufficient to enclose it by a cage of wire gauze. It is unaffected by even powerful electrical discharges from an electrical machine placed near it.

When accumulated on the surface of bodies, electricity tends to pass off to adjacent objects with an effort which is known as the *tension*. This increases with the quantity of electricity. So long

as it does not exceed a certain limit, it is balanced by the resistance presented by the small conducting power of the air when it is dry If the tension increases, this resistance is overcome, and the electricity springs off to an adjacent body with a sound, and in the form of a bright spark. In moist air the tension is always feeble, for the electricity passes away almost as rapidly as it is produced, the moisture condensing on the supports, which thus become good conductors of electricity. In very rarefied air, on the contrary, where there is little resistance, electricity passes off, presenting the appearance of a luminous glow.

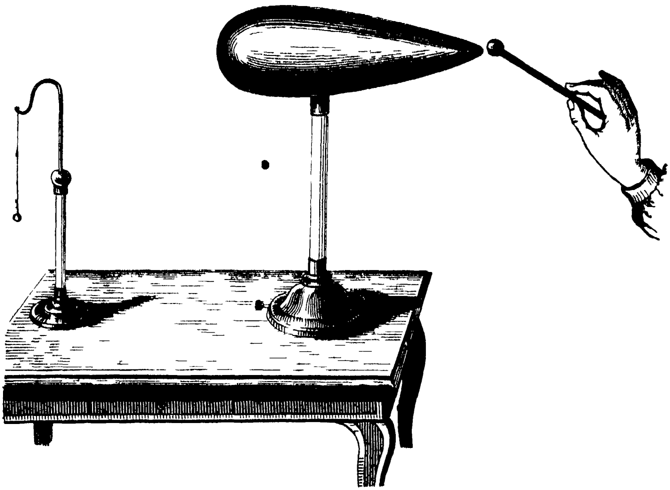


Fig 388.

421. **Influence of the shape of a body on the accumulation of electricity. Effect of points.**—The manner in which electricity is distributed on the surface of a body varies with its shape. If it is spherical, the charge is everywhere the same, which might indeed be predicted, and which may be readily confirmed by means of the *proof plane*, which is a small thin metal disc fixed at the end of a thin shellac rod. This is held in the hand, and successively applied to different parts of the electrified body, and after each contact is presented to an electrical pendulum. If the body is a sphere the attraction is in each case the same, which shows that

the disc has taken the same charge of electricity from each part of the sphere, and, therefore, that the distribution of the electricity is uniform.

This is no longer the case if the electrified body is more or less elongated ; for instance, a kind of ovoid shape, as shown in fig. 388. In this case the proof plane is the more charged the nearer it is applied to the elongated end ; and at this end itself most electricity is removed. This experiment shows that, in good conductors, electricity always tends to accumulate towards the most elongated parts—towards the points. This accumulation produces a greater tension, which is sufficient to overcome the resistance of the air, and allow electricity to escape. It is in fact observed that metal bodies provided with a point quickly lose their electricity, and, if the hand be held over such a point, a sort of wind or draught is felt (431). If this takes place in darkness, a kind of luminous *brush* appears on the top of the point which is known as the *brush discharge* (fig. 404).

The action of flames on electrified bodies is like that of ordinary points, but is more complete ; flames are, in fact, very acute points. The readiest and most effectual method of depriving an electrified nonconductor of its charge of electricity is to pass the flame of a spirit lamp over its surface.

This property of points, placed on electrified conductors, of allowing electricity to escape, has been called the *power or property of points* ; and in electrical experiments we meet with numerous instances in which it comes into play. The action of points has also a most important application in lightning conductors (458).

CHAPTER II.

ACTION OF ELECTRIFIED BODIES ON BODIES IN THE NATURAL STATE; INDUCED ELECTRICITY. ELECTRICAL MACHINES.

422. **Electricity by influence or induction.**—An insulated conductor, charged with either kind of electricity, acts on bodies in a natural state placed near it in a manner analogous to that of the action of a magnet on soft iron; that is, it decomposes the neutral electricity, attracting the opposite, and repelling the like kind

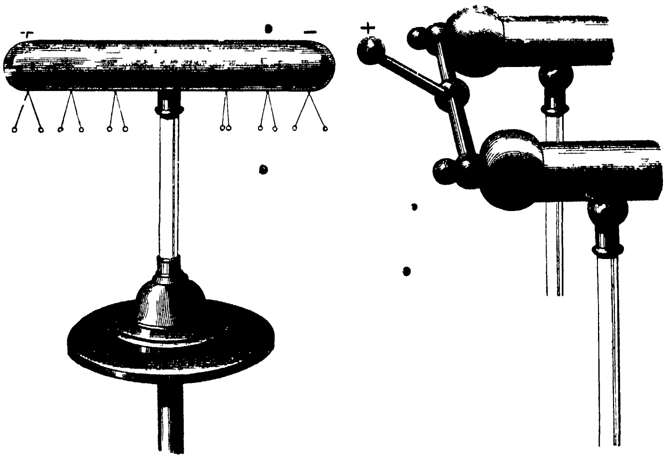


Fig 389

of electricity. The action, which is a consequence of the attractions and repulsions of the two electricities, and which is exerted not only through air, but also through insulating bodies like gutta percha, glass, resins, etc., is said to take place by *influence* or *induction*.

The phenomena of induction may be demonstrated by means of the experiment represented in fig. 389. On the right hand of the figure is the prime conductor of the electrical machine, which, as

we shall afterwards see, is usually charged with positive electricity; on the left is a brass cylinder, insulated by being placed on a glass support, and provided with small pith ball pendulums, suspended by linen threads which are conductors. When the cylinder is brought near the prime conductor, the pendulums are found to diverge, but to unequal extents, the greatest divergence being met with at the ends. Near the middle the pith balls do not diverge at all; the electricity is, therefore, accumulated at the ends, and the middle is in the neutral state. If, moreover, a sealing-wax rod which has been rubbed with flannel be approached to the pendulums nearest the electric machine, they will be repelled, showing that they are charged with the same electricity as the rubbed sealing-wax; that is, with negative electricity. If, in like manner, a glass rod, which has been rubbed with silk, be approached to the other end of the cylinder, the pendulums are also repelled, which shows that they are charged with positive electricity. The electricities thus separated are equal in quantity, for if the cylinder is removed all the pendulums cease to diverge, since the two electricities recombine, and the body is restored to the neutral state.

This *electrifying by influence*, or *induction* as it is called, which is produced by an electrified body on bodies in the neutral state, explains a host of phenomena. In order to explain all its effects, it is important to inquire what takes place when the insulated cylinder, in the above experiment, is placed for a short time in contact with the ground, while it is still under the influence of the machine. Suppose, for instance, the further end be placed in contact with the ground, the positive electricity will escape, while the negative remains held by the attraction of the opposite electricity of the machine. If now connection with the ground be broken, and the cylinder be moved away from the influence of the machine, the pendulums will diverge, and, as can be easily verified, owing to their being charged with negative electricity. Even if the end nearest the machine be connected with the ground, the result is still the same. The negative electricity does not pass into the ground; it is the positive which still escapes; the negative being attracted by the contrary electricity of the machine, on interrupting the communication with the earth, the cylinder remains charged with negative electricity.

Thus a body can be charged with electricity by induction as well as by conduction. But, in the latter case, the charging body loses part of its electricity, which remains unchanged in the former case.

The electricity imparted by conduction is of the same kind as that of the electrified body, while that excited by induction is of the opposite kind. To impart electricity by conduction, the body must be quite insulated, while in the case of induction it must be in connection with the earth, at all events momentarily.

What has here been said has referred to the inductive action exerted on good conductors. Bad conductors are not so easily acted upon by induction, owing to the great resistance they present to the circulation of electricity, but, when once charged, the electric state is more permanent.

This is analogous to what is met with in magnetism ; a magnet instantaneously evokes magnetism in a piece of soft iron ; but this is only temporary, and depends on the continued action of the magnet ; a magnet magnetises steel with far greater difficulty, but this magnetism is permanent.

There are many respects in which the phenomena of magnetic differ from those of electrical induction. In magnetism there is no change except that the action is stronger when the inducing body and that submitted to its action are placed in direct contact, nor does the inducing magnet lose any of its strength. In electricity, on the contrary, when the inducing and induced bodies are brought in contact, conduction takes place ; both bodies are charged with the same kind of electricity, which is shared between them in proportion to their surfaces, and accordingly the inducing body loses some of its electricity. It is thus possible to obtain a body charged with one kind of electricity only ; while in magnetism we cannot perform the analogous operations—we cannot get detached unipolar magnets. Again, the magnetic induction is limited to a very small number of substances, virtually to iron and steel, while electrical induction takes place in all substances.

422*a*. **Faraday's cylinder.**—The quantity of electricity produced in induction is equal to that of the inducing body, as was first demonstrated by a very important experiment of Faraday. A metal ball (fig. 390), suspended by a silk thread, is charged with positive electricity, for instance. It is then introduced into an insulated metal cylinder, considerably larger than itself, which is connected with a gold leaf electroscope, at a distance ; the leaves at once diverge, and, as may be shown, with positive electricity. When the ball is below a certain depth, this divergence does not alter, whatever be its position. On touching the outside of the cylinder with the fingers, the leaves collapse ; they resume their

original divergence when the ball is withdrawn, but their divergence is now due to negative electricity.

If the ball be allowed to touch the inside before removing it, the leaves diverge with positive electricity when it is withdrawn, and the ball is found to have lost its charge.

In the first case the electricity in the ball developed by induction a quantity of negative equal to its own on the cylinder, while on the outside of the cylinder and the electroscope there was a corresponding equal quantity of positive electricity. This positive charge was removed when the cylinder was touched, but the two opposite electricities, the positive on the ball, and the negative on the cylinder, held each other in equilibrium. On removing the ball with its positive charge, the charge of negative electricity on the cylinder made the leaves of the electroscope diverge, and when the ball touched the inside, the quantities of the two opposite electricities being exactly equal, the system was restored to the neutral state.

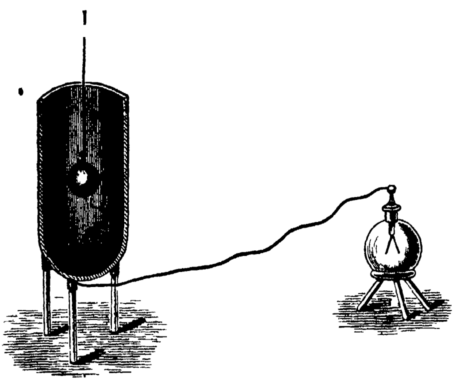


Fig 390

Faraday's cylinder furnishes an excellent means of proving that the quantities of electricity produced when bodies are rubbed together is equal; for if the rod and cap in fig. 385 are placed in the cylinder after being rubbed, no divergence of the leaves is produced. Nor is there any if both cap and rod are simultaneously in the cylinder, not touching each other, and this is the case in whatever position they are placed in the cylinder. If either of them however be withdrawn, the leaves of the electroscope at once diverge, but the divergence ceases when the other is brought back into the cylinder. Whichever be removed, the divergence of the leaves is the same.

ELECTRICAL MACHINE.

423. **Ramsden's electrical machine.** — The first electrical machine was invented by Otto von Guericke, the inventor also of the air-pump. It consisted of a sphere of sulphur, which was

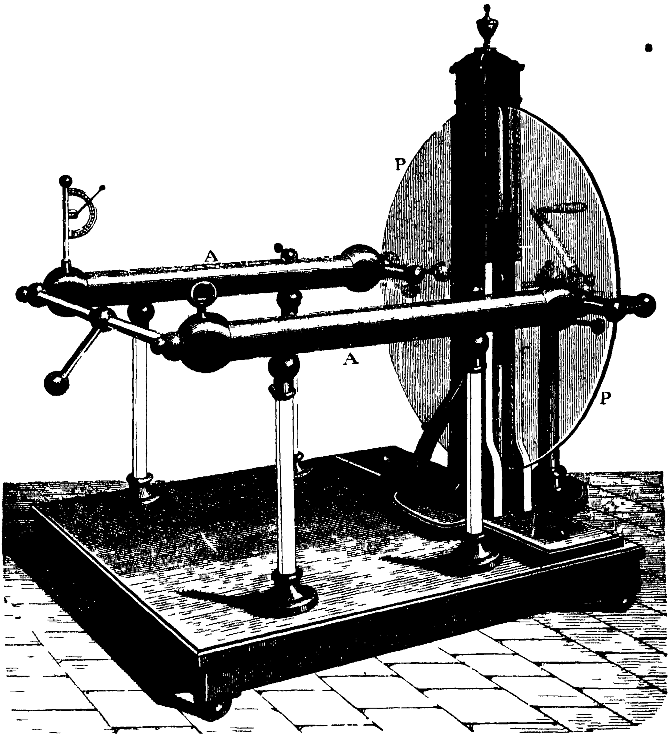


Fig. 391

turned on an axis by means of one hand, while the other hand, pressing against it, served as a rubber. Resin was afterwards substituted for the sulphur, which in turn Hawksbee replaced by a glass cylinder. In all these cases the hand served as rubber

(fig. 410); and Winckler, in 1740, first introduced cushions of horsehair covered with silk as rubbers. At the same time, Bose collected electricity disengaged by friction, on an insulated cylinder of tin plate. Lastly, Ramsden, in 1760, replaced the glass cylinder by a circular glass plate, which was rubbed by cushions. The form which the machine has now is but a modification of Ramsden's original machine.

Between two wooden supports (fig. 391), a circular glass plate, P, about a yard in diameter, is suspended by an axis passing through the centre, and which is turned by means of a glass handle. The plate revolves between two sets of *cushions* or *rubbers*, of leather or of silk, one set above the axis and one below, which, by means of screws, can be pressed as tightly against the glass as may be desired, by which means the plate becomes electrified on both sides. In front of the plate also are two brass rods, provided with a series of points in the sides opposite the glass; these rods are fixed to two large metal cylinders, A A, which form the *prime conductor*. The latter are insulated by being supported on glass feet, and are connected with each other by a smaller rod.

The action of the machine is founded on the excitation of electricity by friction, and on the action of induction. By friction with the rubbers, the glass becomes positively, and the rubbers negatively, electrified. If now the rubbers were insulated, they would receive a certain charge of negative electricity which it would be impossible to exceed, for the tendency of the opposed electricities to reunite would be equal to the power of the friction to decompose the neutral fluid. But the rubbers communicate with the ground by means of bands of tinfoil, fixed to the supports, not shown in the figure, and consequently, as fast as the negative electricity is generated, it passes off. The positive electricity of the glass acts then by induction on the conductor, attracting the negative electricity. The conductors thus lose their negative electricity, and remain charged with positive. The glass plate accordingly gives up nothing to the conductors; in fact, it only abstracts from them their negative electricity.

As thus described, the electrical machine yields only positive electricity; it may, however, be arranged so as to give negative electricity. For this purpose the four feet of the table are insulated by being placed on thick slabs of resin, of glass, of gutta percha or of sulphur, and the conductors are connected with the ground by a metallic chain. This allows the electricity of the positive conductors

to escape, while the negative electricity of the rubbers accumulates on the supports and on the bands of tinfoil.

424. **Measurement of the charge of the electrical machine. Quadrant electrometer.**—The amount of electrical charge is measured by the *quadrant* or *Henley's electrometer*, which is represented in fig. 391 attached to the conductor. This is a small electric pendulum, consisting of a wooden rod, to which is attached an ivory or cardboard scale (fig. 392). In the centre of this is a small straw index, movable on an axis, and terminating in a pith ball. Being attached to the conductor, the index rises as the machine is charged, ceasing to rise when the limit is attained.

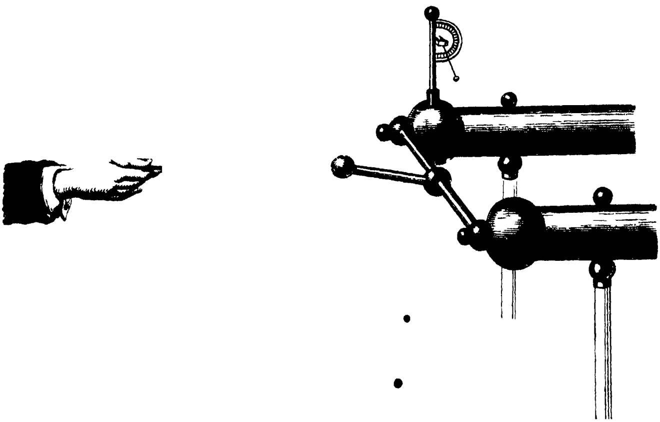


Fig. 392.

When the rotation is discontinued the index falls rapidly if the air is moist ; but in dry air it only falls slowly, showing, therefore, that the loss of electricity in the latter case is less than in the former.

Hence in moist and rainy weather all experiments with the electrical machine are difficult to perform. All parts of the apparatus must be carefully warmed by a charcoal chauffer, and the supports and plate must be rubbed with hot cloths. It is, indeed, by the supports that the greater part of the electricity is lost.

The rubbers require great care both in their construction and in their preservation. They are commonly made of leather stuffed with horse-hair. Before use they are coated either with powdered *aurum musivum* (sulphuret of tin), or graphite, or amalgam. The

action of these substances is not very clearly understood. Some consider that it merely consists in promoting friction. Others, again, believe that a chemical action is produced, and assign in support of this view the peculiar smell noticed near the rubbers when the machine is worked. Amalgams, perhaps, promote most powerfully the disengagement of electricity. *Kienmayer's amalgam* is the best of them.

Whatever precautions be taken to avoid the loss of electricity, or however rapidly the machine is turned, it is impossible to exceed a certain limit. For, as the electricity accumulates on the machine, its tension increases too, and very soon its tendency to escape exceeds the resistance offered by the air and the supports of the conductors. From this moment the loss of electricity equals the electricity disengaged by friction, and hence the tension can never exceed the limit it has attained, which is indicated by the electrometer remaining stationary, although the rotation is continued.

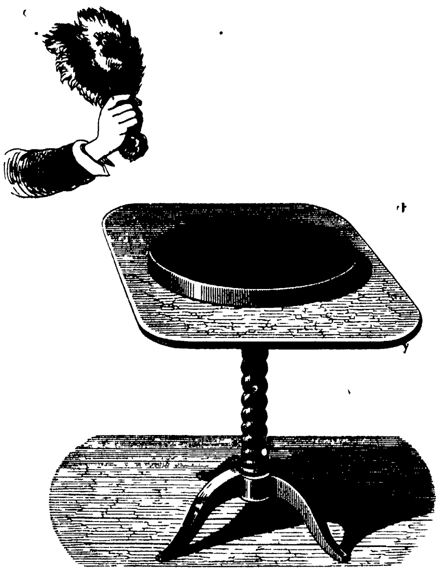


Fig. 393.

If, moreover, the maximum effect is desired, the machine must not be placed too near the walls or the furniture: it must be, in short, away from all objects on which it could act by induction, especially if these are angular, for it then continually withdraws the electricity of the opposite kind, and tends to revert to the neutral state. Thus if a point, or the flame of a candle, be presented to the prime conductor of a machine in action, as represented in fig. 392, the electrometer falls, even though the point is at some distance. This is due to the fact that the positive elec-

tricity of the machine induces negative in the point repelling positive through the body into the earth; the negative flows out through the point as fast as it is produced, and, combining with the positive electricity on the prime conductor by means of which it was evoked, continually brings the machine back to the neutral state.

425. **Electrophorus.**—This is a very simple apparatus invented by Volta, and by means of which considerable quantities of electricity may be produced. It consists of a *cake* of resin (fig. 393), of about twelve inches diameter, and an inch thick, which is placed on a metal surface, or very frequently fits in a wooden

Fig 394.

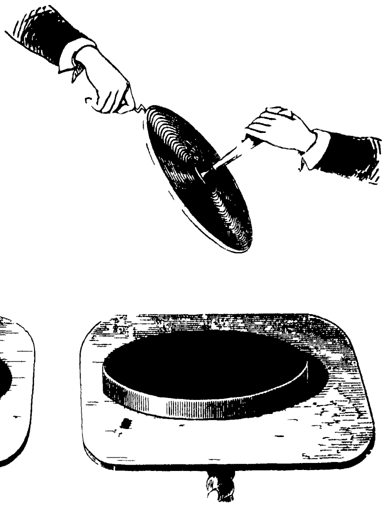


Fig 395

mould lined with tinfoil, which is called the *form*. Besides this, there is a wooden disc, of a diameter somewhat less than that of the cake, lined on its under surface with tinfoil, and provided with an insulating glass handle. This is called the *cover*. The mode of working this apparatus is as follows:—All the parts of the apparatus having been well warmed, the cake, which is placed in the form, or rests on a metal surface, is briskly flapped with a catskin, as shown in fig. 393, by which it becomes charged with negative electricity. The cover held by the insulating handle is then placed on the cake. The negative electricity of the cake, acting thus in-

ductively on the cover, attracts positive electricity to the lower surface, and repels negative to the upper. If now this upper surface be touched by the finger, as shown in fig. 394, the negative electricity passes out into the ground, and the disc only retains positive electricity. Now when the cover is raised by one hand by means of the insulating handle, and the other hand is brought near it, a smart spark passes, due to the recombination of the positive of the disc with the negative produced by its induction in the hand (fig. 395).

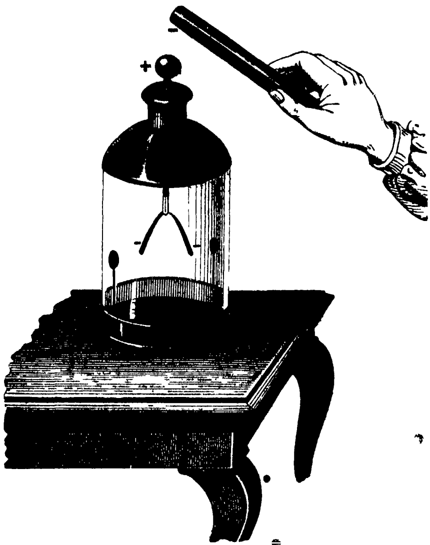


Fig. 396.

Replacing the disc upon the cake, this again exerts its inductive action, for it is such a bad conductor that the electricity does not pass off to the cover, and, if the same operations be repeated, a succession of such sparks may be obtained even after the lapse of some time. The retention of electricity is greatly promoted by keeping the cake in the form, and placing the cover upon it, by which the access of air is hindered. Instead of a cake of resin, a disc of gutta percha, or vulcanised cloth, or vulcanite, may be substituted ; and of course, if any non-conducting material which becomes positively electrified by friction be used as the cake, the cover acquires a negative charge.

426. **Gold-leaf electroscope.**—The *gold-leaf electroscope*, also called *Bennett's electroscope*, from the name of its inventor, is a small but delicate apparatus for ascertaining whether a body is electrified, and if so with what kind of electricity it is charged. It consists of a tubulated glass shade (fig. 396), the neck of which is closed by a cork. In this is fitted a brass rod terminating at the top in a knob, and at the bottom in two strips of gold leaf or of aluminum foil. The neck, the cork, and the upper part of the shade are coated

with a thick layer of sealing-wax varnish, which is a solution of sealing-wax in spirits of wine. The object of this coating is to improve the insulating qualities of the glass. Glass is, indeed, a bad conductor, but it is very *hygroscopic*; that is, it readily attracts aqueous vapour from the air, and thus becomes coated with a layer of moisture, which renders its surface a conductor (418). When covered with varnish this evil is removed, for varnishes, which are usually made of resin, are not hygroscopic.

The air in the inside is dried by quicklime, or by chloride of calcium, or by pumice stone soaked in strong sulphuric acid, and on the inside of the shade there are two strips of gold leaf or of tinfoil communicating with the ground.

When the knob is touched with a body charged with either kind of electricity, the leaves diverge; usually, however, the apparatus is charged by induction in the following manner:—

If an electrified body—a stick of sealing-wax rubbed with flannel, for instance—be brought near the knob, it will decompose the natural electricity of the system, attracting the electricity of the opposite kind to the knob and retaining it there, and repelling the electricity of the same kind to the gold leaves, which consequently diverge. In this way, the presence of an electrical charge is ascertained, but not its quality. The strips of gold leaf or of tinfoil on the inside increase the delicacy of the instrument; for the electricity of each leaf acting on the nearest strip by induction produces electricity of the opposite kind, and this acts attractively on the leaf, and thus increases their divergence.

To ascertain the kind of electricity the following method is pursued:—If, while the instrument is under the influence of the body, which we will suppose has a negative charge, the knob be touched by the finger, the negative electricity produced in induction passes off into the ground, and the previously divergent leaves will collapse: there only remains positive electricity retained in the knob by induction from the sealing-wax. If now the finger be first removed, and then the electrified body, the positive electricity previously retained by the sealing-wax will spread over the system, and cause the leaves to diverge with positive electricity. Now, while the system is charged with positive electricity, if a positively electrified body, as, for example, an excited glass rod, be approached, the leaves will diverge more widely; for the electricity of the same kind will be repelled to the extremities. If, on the contrary, an excited shellac rod be presented, the leaves will tend

to collapse, the electricity with which they are charged being attracted by the opposite kind. Hence we may ascertain the kind of electricity, either by imparting to the electroscope electricity from the body under examination, and then bringing near it a rod charged with positive or negative electricity ; or the electroscope may be charged with a known kind of electricity, and the electrified body in question brought near the electroscope.

It has been proposed to use the electroscope as an *electrometer*, or measurer of electricity, by measuring the angle of divergence of the leaves. This is done by placing behind them a graduated scale. For very small charges the angle of divergence may be taken as proportional to the charges, but this proportionality no longer holds when the charges increase. There are, however, many objections to such a use, and it is rarely employed for this purpose.

CHAPTER III.

ELECTRICAL EXPERIMENTS.

427. **Electrical spark.**—One of the first experiments which is made by those who see an electrical machine at work for the first time is that of taking from it an electrical spark by bringing the

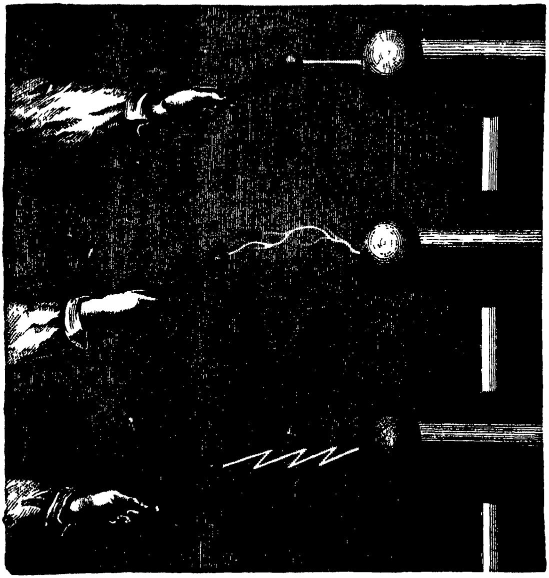


Fig. 397.

Fig. 398.

Fig. 399.

hand near the conductor. The positive electricity of the conductor acting inductively on the neutral electricity of the body, decomposes it, repelling the positive and attracting the negative. When the tension of the opposed electricities is sufficiently great to over-

come the resistance of the air, they recombine with a smart crack and a spark. The spark is instantaneous, and is accompanied by a sharp prickly sensation, more especially with a powerful machine. Its shape varies. When it strikes at a short distance, it is rectilinear, as seen in fig. 397. Beyond two or three inches in length the spark becomes irregular, and has the form of a sinuous curve with branches (fig. 398). If the discharge is very powerful, the spark takes a zigzag shape (fig. 399). These two latter appearances are seen in the lightning discharge.

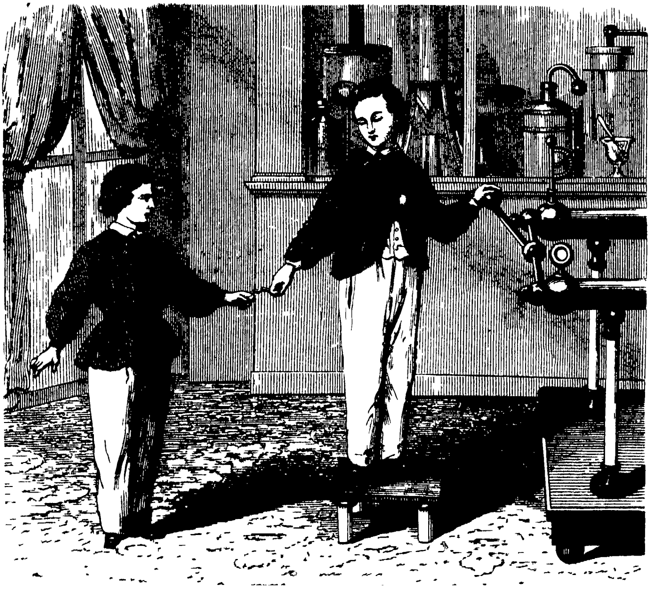


Fig. 400.

428. **Insulating stool.**—A spark may be taken from the human body by the aid of the *insulating stool*, which is simply a low stool with stout varnished glass legs. The person standing on this stool touchesthe prime conductor, and, as the human body is a good conductor, the electrical fluid is distributed over its surface as over an ordinary insulated metallic conductor (fig. 400). The hair diverges in consequence of repulsion, a peculiar sensation is felt on the face,

and if another person, standing on the ground, presents his hand to any part of the body, a smart crack with a pricking sensation is produced. If paper tassels are held in the hand they diverge widely. Instead of such a stool, a sheet of indiarubber cloth or of gutta-percha may be used. If a person standing on an insulated stool be struck with flannel or with silk by one standing on the ground, the former becomes electrified; and if he touches a gold-leaf electroscope, the leaves diverge, and, as may be shown, with negative electricity.

429. **Electrical chimes.**—*The electrical chimes* is a bell-work which is worked by electrical attraction and repulsion. It consists of three metal bells suspended from a horizontal rod, *m*, which is

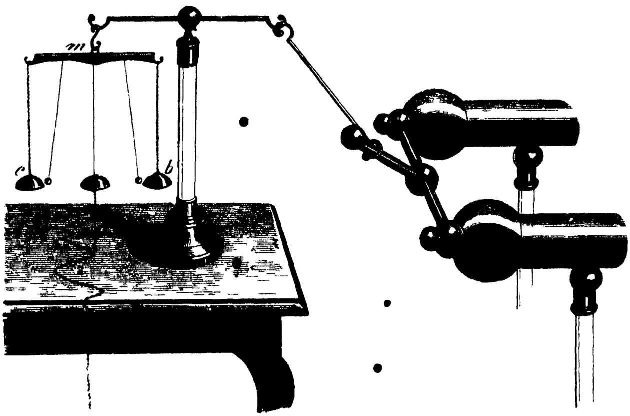


Fig. 401.

connected with the electrical machine (fig. 401). The two bells, *b* and *c*, are suspended by light metal chains: the middle one is suspended by silk, and is moreover connected with the ground by a chain. Between the bells are two small hollow brass balls, suspended by silk threads. When the machine is worked these small brass balls are attracted by the electricity which passes by conduction to the bells, *b* and *c*, and strike against them; but being at once repelled, they strike against the middle bell, to which they give up their electricity, which thus passes into the ground. They are then again attracted, again repelled, and so on as long as the electrical machine is worked.

430. **Dancing puppets.**—This, like the chimes, is an application of the attractions and repulsions of electrified bodies. It consists in placing a small, very light figure of pith, loaded at the feet, between two metal discs, one connected with the ground and the other with the electrical machine (fig. 402). As soon as this latter becomes charged, the small puppet is successively attracted and repelled from one to the other disc, as if it executed of its own proper action a series of jumps.

With this we may mention the experiment of the *electrical hail*,

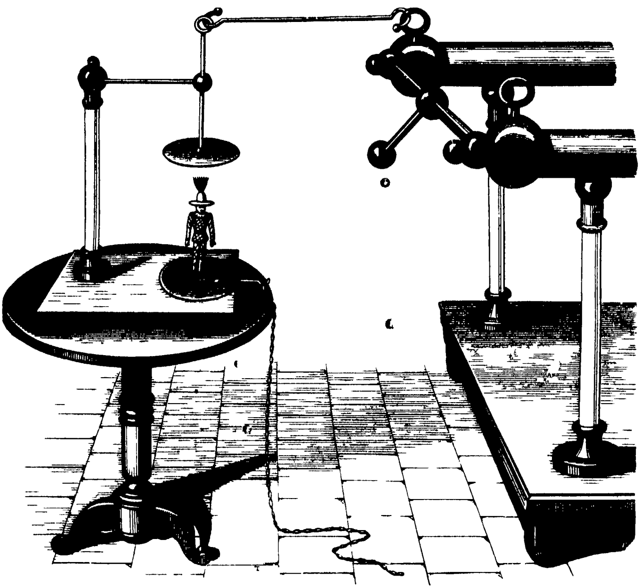


Fig 402

which was originally devised by Volta for the purpose of illustrating what he supposed to be the motion of hail between two clouds oppositely electrified. It consists of a tubulated glass shade, with a metal base, in connection with the earth on which are some pith balls. The tubulure has a metal cap, through which passes a brass rod, provided with a metal disc or sphere at the lower end, and at the upper with a ring, which touches the prime conductor.

When the machine is worked, the sphere becoming positively electrified attracts the light pith balls, which are then immediately repelled, and, having lost their charge of positive electricity, are again attracted, again repelled, and so on, as long as the machine continues to be worked.

431. **Electrical whirl or vane.**—The electrical *whirl* or *vane* consists of four to six wires, terminating in points, all bent in the same direction, and fixed in a central cap, which rotates on a pivot (fig. 403). When the apparatus is placed on the conductor, and the machine is worked, the whirl begins to revolve in a direction opposite that of the points. This motion is analogous to that of the hydraulic tourniquet (81), but, unlike that, it is not caused by a flow of material fluid, but is due to a repulsion between the electricity of the points and that which they directly impart to the air by conduction. The electricity, being accumulated on the points in a high state of tension, passes into the adjacent air, and thus imparting to it a charge of electricity, repels this electricity, while it is itself repelled. That this is the case is evident from the fact that, on approaching the hand to the whirl while in motion, a slight draught is felt, due to the movement of the electrified air; while in vacuo the apparatus does not act at all. This draught or wind is known as the electrical *aura.* The escape of electricity in this way is analogous to the manner in which heat is transmitted in liquids (224), and is sometimes known as *electrical convection.*

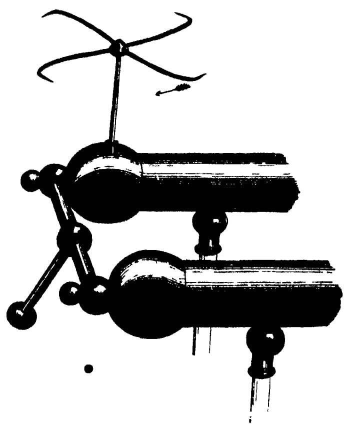


Fig. 403.

When the electricity thus escapes by a point, the electrified air is repelled so strongly as not only to be perceptible to the hand, but the current is strong enough to blow out a candle. The same effect is produced by placing a taper on the conductor, and bringing near it a pointed wire held in the hand. The current arises, in this case, from the contrary electricity, which is withdrawn through the point under the influence of the machine.

The *electrical orrery* and the *electrical inclined plane* are analogous to these pieces of apparatus.

If a small metal vessel containing water, having minute apertures through which it issues in drops, be suspended by a wire to the prime conductor, the water issues in jets when the vessel is electrified by working the machine, in consequence of the repulsion between the electrified vessel and the issuing water, which is electrified also.

If a wire about $\frac{1}{8}$ to $\frac{1}{4}$ of an inch in diameter, and rounded at the end, is placed on the conductor of the electrical machine, which is worked in a dark room, the electricity in streaming out illuminates the air, and a kind of luminous brush appears on the top of the point. This is known as the *brush* discharge (fig. 404).

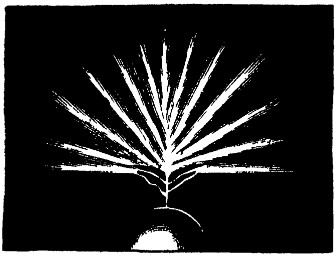


Fig. 404.

It is remarkable that the form of the brush discharge differs with the kind of electricity with which the conductor is charged ; it is larger with positive than with negative electricity ; with the latter the discharge has more the shape of a luminous star, or a steady glow, which is called the *glow* discharge.

432. **Electric egg.**—The influence of the pressure of the air, or rather of its nonconductivity, on the electric light, may be studied by means of the *electric egg.* This consists of an ellipsoidal glass vessel (fig. 405), with metal caps at each end. The lower cap is provided with a stopcock, so that it can be screwed into an air-pump, and also into a heavy metal foot. The upper metal rod moves up and down in a leather stuffing-box ; the lower one is fixed to the cap. An almost complete vacuum having been made, the stopcock is turned, and the vessel screwed into its foot ; the upper part is then connected with a powerful electrical machine, and the lower one with the ground. On working the machine, the globe becomes filled with a feeble violet light continuous from one end to the other, and resulting from the recomposition of the positive fluid of the upper cap with the negative of the lower. If the air be gradually allowed to enter by opening the stopcock, the resistance increases and the light, which appeared continuous, white and brilliant, is now only seen as an ordinary spark.

433. **Magic pane.**—The magic pane (fig. 406) consists of a glass plate, one side of which is covered with several strips of tinfoil, arranged so as to form a series of metal bands, parallel and close to each other. The pane is supported vertically by two glass rods, and the upper end of the tinfoil is connected with the electrical machine by a conductor, and the lower one with the ground by a chain.

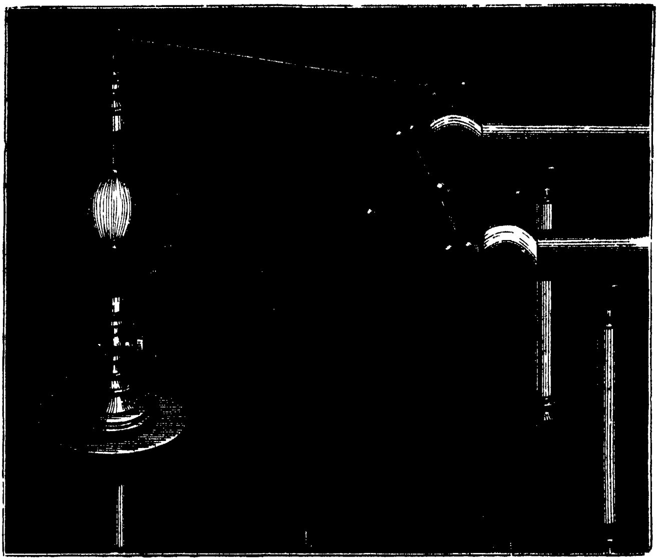


Fig. 405.

In this condition, if the machine be worked, the electricity will pass into the ground by the tinfoil, without any interruption; but if a series of breaks are made in the tinfoil by cutting it away with a penknife, a spark appears at each break; and if these breaks be so arranged as to represent a given object, a flower, or a monument, or words, these objects are reproduced in a line of fire when the electrical machine is set to work. This experiment is really due to the prodigious velocity of light, which is not less than about 186,000 miles in a second; hence in the above experiment,

although the sparks are really successive, they follow each other with such rapidity as to seem continuous (363).

434. **Luminous globe and tube.**—The *luminous globe* is a glass globe lined on the inside with a series of small lozenges of tinfoil placed very near each other without actually touching. The

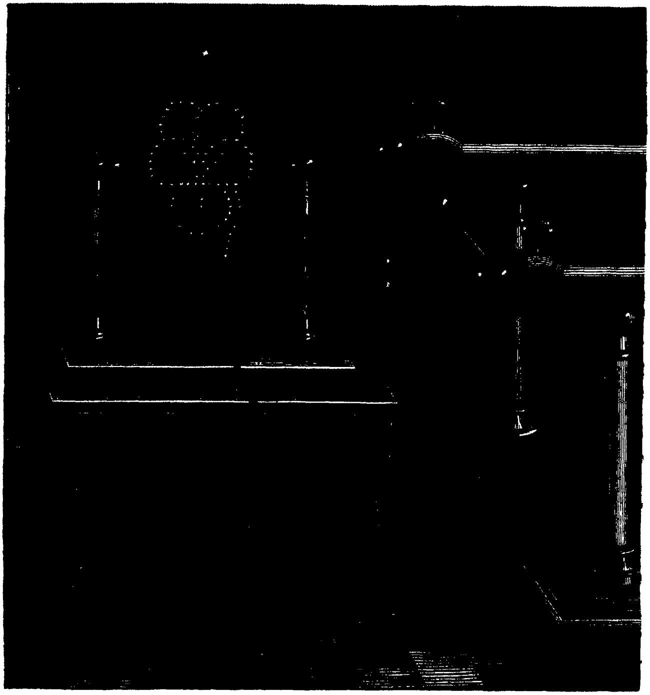


Fig. 406.

first plate is connected with an electrical machine at work, and the last with the ground, upon which a series of bright sparks appears at each break in the metallic conductor (fig. 407).

If the small metal plates are arranged inside a glass tube in the form of a spiral from one end to the other, this arrangement forms a *luminous tube*, sometimes called the electrical serpent.

435. **Volta's cannon.**—This is not merely interesting as an experiment, but also as demonstrating an important fact, namely, that the electrical spark can establish chemical action. Thus, water is formed of two gases, hydrogen and oxygen, in the ratio of one volume of the latter to two volumes of the former. Now when an electrical spark is passed through a mixture of these two gases,

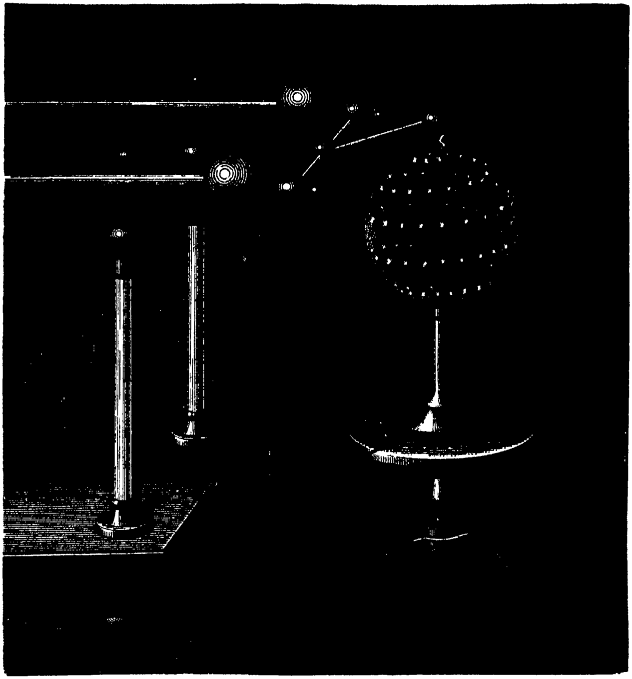


Fig 407.

they combine in these proportions, and form water. This combination is, moreover, attended by a bright flash of light and a loud report, the latter being due to the expansive force of aqueous vapour, arising from the high temperature produced by the combination.

Volta's cannon, represented in fig. 408, is an illustration of this

property which some mixtures of gases have of being exploded by the electrical spark. It is a small brass cannon, resting on an insu-

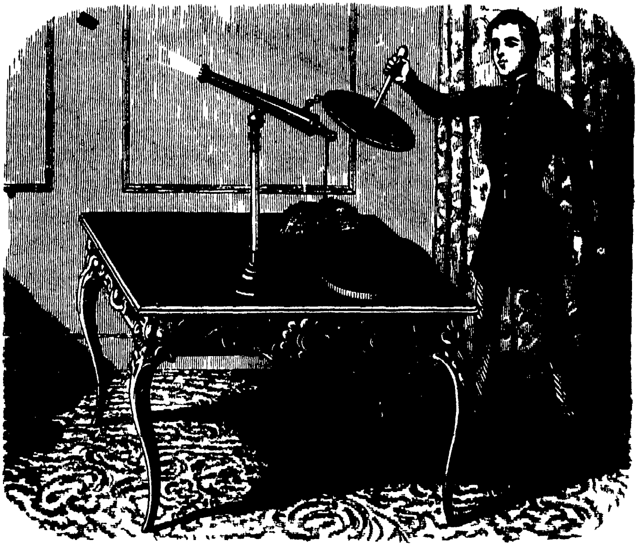


Fig. 408.

lating support. In the touchhole is a small glass tube, and in this a brass wire with a small knob at each end (fig. 409); one of which knobs is on the outside, and the other very near the inside of the cannon, but not touching it. Having filled the cannon with a mixture of two volumes of hydrogen and one of oxygen, it is closed by a cork and is connected with the ground by a metal chain. If then the charged disc of the electrophorus be approached, a spark passes to the small knob, and at the same time inside the cannon. This latter causes the two gases to combine with a violent explosion, which drives out the cork. Instead of hydrogen and oxygen, a mixture of coal gas and air may be used.

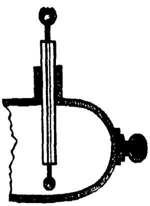


Fig. 409.

CHAPTER IV.

CONDENSATION OF ELECTRICITY.

436. **Discovery of the Leyden jar.**—In 1745 Cunæus of Leyden, wishing to electrify water contained in a flask, suspended to the conductor of an electrical machine a wire, and then held the flask

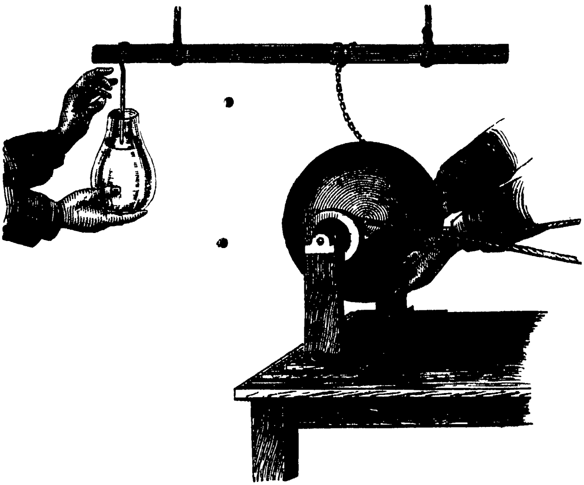


Fig. 410.

in one hand so that the wire just dipped in the water (fig. 410). The machine having been worked for some time he accidentally touched the conductor, and in so doing received a violent shock. Muschenbroeck, his teacher, who repeated the experiment, received in the arms and breast a shock so violent that it was two days before he recovered from its effects; and, writing to his friend Réaumur, he said he would not repeat the experiment for the whole kingdom of France.

In the previous year Kleist, a German clergyman, in a private

letter to a friend, described an experiment which he had made, and which was substantially the same as the above; but it was the Dutch philosophers who investigated the conditions of success, and who gave the explanation of the phenomenon; and accordingly it is in their honour that the name *Leyden jar* is given to the apparatus to which their discovery gave rise.

437. **Electrical condensers.**—It is not difficult to see that in the above experiments the water and the hand play the part of two conductors separated by an insulating plate; any arrangement in which these conditions are fulfilled would produce similar effects;

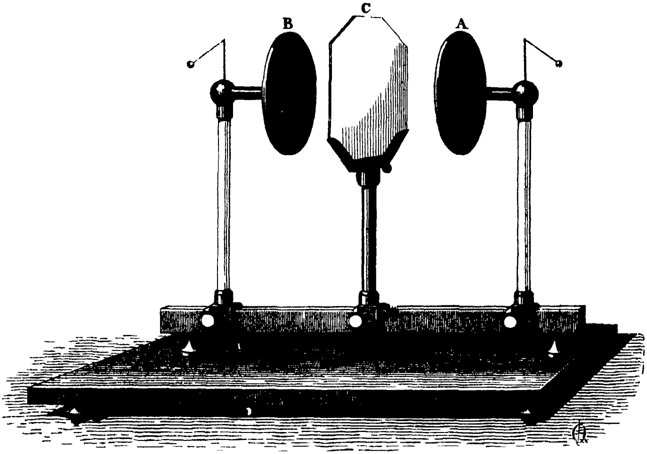


Fig. 411.

for it would have the power of accumulating or condensing electricity, from which has been derived the term *accumulator or condenser.*

The action of the condenser may be most conveniently explained by reference to that of Epinus, which consists of two metal plates, A and B, insulated by being supported on glass legs (fig. 411); between them is a pane of ordinary glass, C, of somewhat larger diameter than that of the plates A and B, which are about six inches in diameter. The legs can be moved along a support, and be fixed in any position.

In explaining the action of the condenser, it will be convenient to call that side the metal plate nearest the glass the *anterior*, and the other the *posterior*, side. And first let A be at such a distance

from B as to be out of the sphere of its action. The plate B, which is then connected with the conductor of the electrical machine, takes its maximum charge, which is distributed equally on its two faces, and the pendulum diverges widely. If the connection with the machine be interrupted, nothing would be changed; but if the plate, A, be slowly approached, its neutral fluid being decomposed by the influence of B, the negative is accumulated on its anterior face, *n* (fig. 412), and the positive passes into the ground. But as the negative electricity of the plate A reacts in its turn on the positive of the plate B, the latter fluid ceases to be equally distributed on both faces, and is accumulated on its anterior face, *m*, fig. 413. The posterior face, *n*, having thus lost a portion of its electricity, its tension

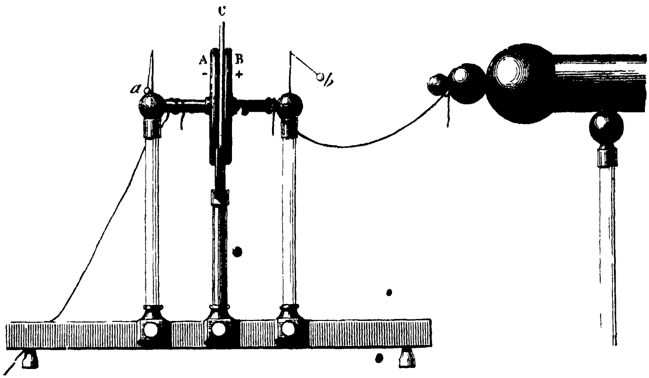


Fig. 412.

has diminished, and is no longer equal to that of the machine, and the pendulum *b* diverges less widely. Hence B can receive a fresh quantity from the machine, which, acting as just described, decomposes by induction a second quantity of neutral fluid on the plate A. There is then a new accumulation of negative fluid on the face *n*, and consequently of positive fluid on *m*. But each time the machine gives off electricity to the plate B, only a proportion of this passes to the face *m*, the other remaining on the face *p*; the tension here, therefore, continues to increase until it equals that of the machine. From this moment equilibrium is established, and a limit to the charge is reached, which cannot be exceeded. The quantity of electricity accumulated now on the two faces, *m* and *n*, is very considerable, and yet the pendulum diverges just as much

as it did when A was absent, and no more ; in fact, the tension at *p* is just what it was then, namely, that of the machine.

When the condenser is charged—that is, when the opposite electricities are accumulated on the anterior faces—connection with the ground is broken by detaching the wires. The plate A is charged with negative electricity, but simply on its anterior face (fig. 413), the other side being neutral. The plate B, on the contrary, is electrified on both sides, but unequally ; the accumulation is only on its anterior face, while on the posterior, *p*, the tension is simply equal to that of the machine at the moment the connections are interrupted. In fact the pendulum *b* diverges and *a* remains vertical (fig. 412). But if the two plates are removed, the two pendulums diverge (fig. 413), which is owing to the circumstance that, as the plates no longer act on each other, the positive fluid is equally distributed on the two faces of the plate B, and the negative on those of the plate A.

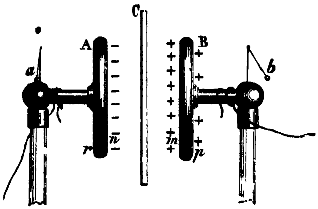


Fig. 413.

Hence the conditions for accumulating electricity are that we have a conducting surface in connection with the source of electricity, separated by a non-conductor from a second conducting surface in contact with the earth. In however varied a manner these conditions are fulfilled we have a condenser. Thus when an electrical machine is at work, and the knuckle is held at a certain distance from the prime conductor, sparks pass across with a frequency which, with the same rate of working the machine, depends on the distance. Here in every stage of the working electricity is being continuously produced ; but only when it has sufficiently accumulated can it discharge across the layer of air between it and the knuckle. Here the prime conductor is the source of electricity, the layer of air is the dielectric, and the knuckle is the conductor in connection with the earth.

438. **Slow discharge and instantaneous discharge.**—While the plates, A and B, are in contact with the glass (fig. 412), and the connections are interrupted, the condenser may be discharged—that is, restored to the neutral state—in two ways, either by a slow or by an instantaneous discharge. To discharge it slowly, the plate B—that is, the one containing an excess of electricity—is touched

with the finger ; a spark passes, all the electricity on *p* escapes into the ground, the pendulum *b* falls, but *a* diverges. For B having lost part of its electricity, only retains on the face, *m*, that held by the inductive influence of the negative on A. But the quantity thus retained at B is less than that on A: this has free electricity which makes the pendulum *a* diverge ; and, if it now be touched, a spark passes, the pendulum *a* sinks while *b* rises, and so on by continuing to touch alternately the two plates. The discharge only takes place slowly ; in very dry air it may require several hours. If the plate, A, were touched first, no electricity would be removed, for all it has is retained by that of the plate B. To remove the total quantity of electricity by the method of alternate contacts, an infinite number of such contacts would theoretically be required.

To obtain an instantaneous discharge one hand may be placed on one plate, and the second touched with the other hand; a violent shock is then felt, far more violent than that produced by the electrical machine. To avoid this a *discharging rod* is used, which consists of two bent stout brass wires terminating in knobs and joined by a hinge. If this be held in the hand as represented in fig. 415, and one knob be applied to one plate of the condenser while the arc is bent, so that the second touches the other plate, just as this is on the point of touching, a spark passes, which is due to the reunion of the two electricities accumulated on the condenser; no shock is felt, for the recombination does not take place through the arms and body of the experimenter, but through the metal arc, which is a far better conductor.

439. **Amount of charge of condensers. Specific inductive capacity.**—The quantity of electricity which can be accumulated on each plate, other things being equal, is proportional to the tension of the electricity on the conductor, and to the surface of the plates: it decreases as the insulating plate is thicker. There is another circumstance which influences the quantity of electricity which a condenser can accumulate, and that is the nature of the insulator, or what is also called the *dielectric*, itself. Insulators differ in the extent to which they allow inductive actions to take place, and this property, which is known as the *specific inductive capacity*, is not the same as the property of insulation. Thus, if a condenser is formed in which the metal plates are separated by a certain thickness of air, and if a similar one be formed with a layer of gutta-percha of the same thickness, it will be found that with the same source of electricity four times as much electricity

will be condensed as in the former, or, what is the same thing, if the insulating layer of gutta-percha were four times as thick as the air, it would condense as much electricity.

Two causes limit the quantity of electricity which can be accumulated. First, that the electric tension of the collecting plate gradually increases, and ultimately equals that of the machine, which cannot, therefore, impart any free electricity. The second cause is the imperfect resistance which the insulating plate offers to the recombination of the two opposite electricities; for when the force which impels the two electricities to recombine exceeds the resistance offered by the insulating plate, it is perforated, and the contrary electricities unite.

440. **Leyden jar.**—The ordinary form of the Leyden jar (436) or flask consists of a glass bottle of any convenient size, the interior

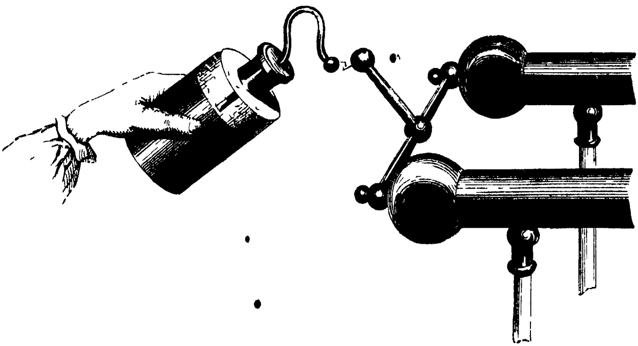


Fig. 414.

of which is either coated with tinfoil or filled with thin leaves of copper, or with gold-leaf. Up to a certain distance from the neck the outside is coated with tinfoil. The neck is provided with a cork, through which passes a brass rod, which terminates at one end in a knob, and communicates with the metal in the interior. The metallic coatings are called respectively the *internal* and *external armatures* or *coatings*. Like any other form of condenser, the jar is charged by connecting one of the armatures with the ground, and the other with the source of electricity. When it is held in the hand by the external coating, and the knob presented to the conductor of the machine (fig. 414) which is worked, positive electricity is accumulated on the inner, and negative electricity on the outer,

coating. The reverse is the case if the jar is held by the knob, and the external coating presented to the machine. The explanation of the action of the jar is the same as that of the condenser (fig. 413), and what has been said of this applies to the jar, substituting the two armatures for the two plates, A and B, of the condenser.

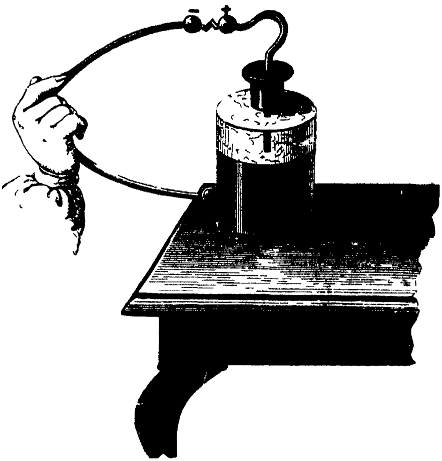


Fig. 415.

Like any other form of condenser, the Leyden jar may be discharged either slowly or instantaneously. For the latter it is held in the hand by the outside coating, and the two coatings are then connected by means of the simple discharger (fig. 415). Care must be taken to touch *first* the external coating with the discharger, otherwise a smart shock will be felt. To discharge it slowly the jar is placed on an insulated plate, and first the inner and then the outer coating touched, either with the hand or with a metallic conductor. A light spark is seen at each discharge.

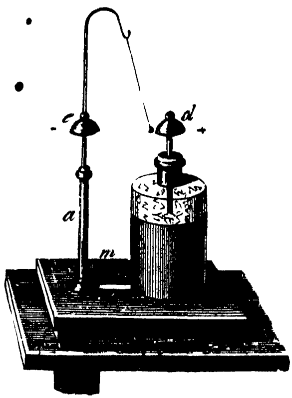


Fig. 416.

Fig. 416 represents a very pretty experiment for illustrating the slow discharge. The rod terminates in a small bell, *d*, and the outside coating is connected with an upright metal support, on which is a similar bell, *e*. Between the two bells a gilt pith ball is suspended by a silk thread. The jar is then charged in the usual manner, and placed on the support, *m*. The internal armature contains a quantity of free

electricity; the pendulum is attracted and immediately repelled, striking against the second bell, to which it imparts its free electricity. Being now neutralised, it is again attracted by the first bell, and so on for some time, especially if the air be dry and the jar pretty large.

When a jar has been discharged and allowed to stand a short time, it exhibits a second charge, which is called the *electric residue.* The jar may be again discharged, and a second residue will be left, feebler than the first, and so on, for three or four times. The residue is greater the longer the jar has remained charged. The magnitude of the residue further depends on the amount of the charge, and also on the degree in which the metal plates are in

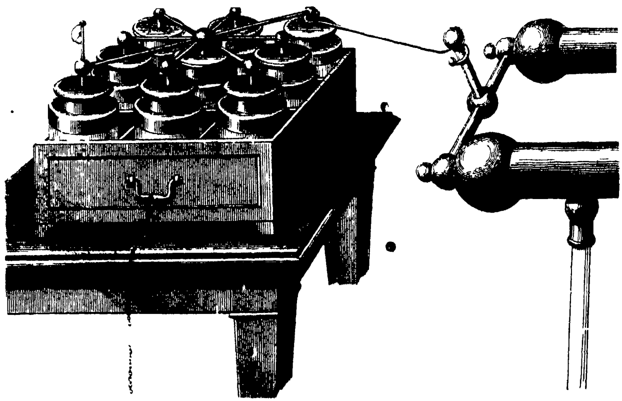


Fig. 417.

contact with the insulator. It seems to be due to penetration of some of the electricity into the dielectric, and from which it does not at once pass to the surface when the jar is first discharged.

441. **Electric batteries.**—The charge which a Leyden jar can take depends on the extent of the coated surface, and for small thicknesses is inversely proportional to the thickness of the insulator. Hence the larger and thinner the jar the more powerful the charge. But very large jars are expensive, and liable to break; and when too thin, the accumulated electricities are apt to discharge themselves through the glass, especially if this is not quite homogeneous. Leyden jars have usually from $\frac{1}{2}$ to 3 square feet

of coated surface. For more powerful charges electric batteries are used.

An *electric battery* consists of a series of Leyden jars, whose inner and outer coatings are respectively connected with each other (fig. 417). They are usually placed in a wooden box lined on the bottom with tinfoil. This lining is connected with two metal handles in the sides of the box. The inner coatings are connected with each other by metal rods, and the battery is charged by placing the inner coatings in connection with the prime conductor, while the outer coatings are connected with the ground by means of a chain fixed to the handles. A quadrant electrometer fixed to one jar serves to indicate the charge of the battery. Although there is a large quantity of electricity accumulated in the

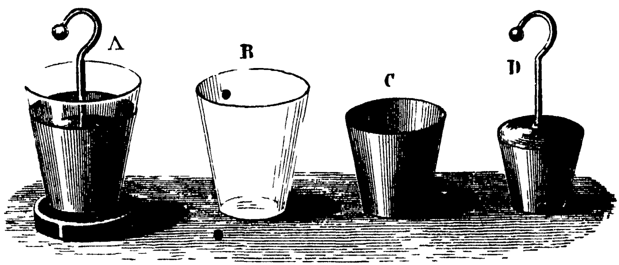


Fig 418.

apparatus, the divergence is not great, for it is simply due to the free electricity on the inner coating. The number of jars is usually four, six, or nine. The larger and more numerous they are, the longer is the time required to charge the battery, but the effects are so much the more powerful.

When a battery is to be discharged, the inner and outer coatings are connected by means of a discharging rod, the outside coating being touched first. Great care is required, for with large batteries serious accidents may be produced, resulting even in death.

441*a*. **Dissected Leyden jar.**—It appears that the insulating medium or dielectric (439) in the Leyden jar plays a most important part, and it is there and not on the metallic coatings that the electricity is stored up. This is illustrated by the experiment of the *dissected Leyden jar*. This consists of a somewhat conical glass vessel, B, with movable coatings of tin, C and D. These separate

pieces placed one in the other, as shown in A, fig. 418, form a complete Leyden jar. After having charged the jar, it is placed on an insulating cake ; the internal coating is first removed by the hand, or better by a glass rod, and then the glass vessel. The coatings are found to contain little or no electricity, and if they are placed on the table they are restored to the neutral state. Nevertheless, when the jar is put together again, as represented

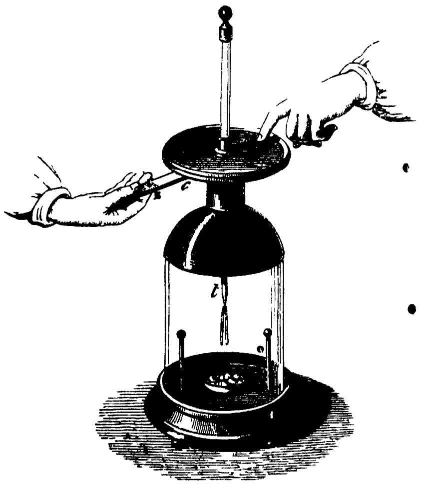


Fig. 419

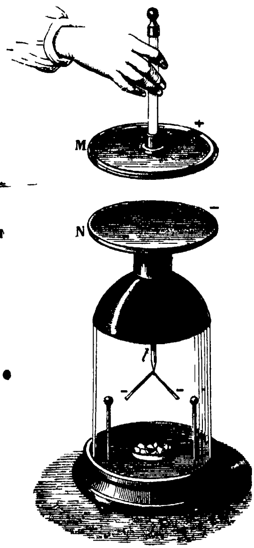


Fig 420

in the figure at A, a shock may be taken from it almost as strong as if the coatings had not been removed. It is therefore concluded that the coatings principally play the part of conductors, distributing the electricity over the surface of the glass, which thus becomes polarised, and retains this state even when placed on the table.

The experiment may be conveniently made from an ordinary glass vessel by forming it into a Leyden jar, of which the inside and outside coatings are of mercury ; charging it ; then, having mixed the two coatings, the apparatus is put together again, upon which a discharge may be once more taken.

442. **Condensing electroscope.**—We shall conclude this account of condensers by describing an application which Volta made of this principle to the ordinary gold-leaf electroscope, by which a far greater degree of delicacy is attained (fig. 420). The rod to which the gold leaves are affixed terminates in a disc instead of in a knob (fig. 396), and there is another disc of the same size provided with an insulating glass handle. Each disc is covered with a layer of insulating shellac varnish (fig. 420).

To render very small quantities of electricity perceptible by this apparatus, one of the plates, which thus becomes the *collecting plate*, is touched with the body under examination. The other plate, the *condensing plate*, is connected with the ground, by touching it with the finger. The electricity of the body, being diffused over the collecting plate, acts inductively through the varnish on the neutral fluid of the other plate, attracting the opposite electricity, but repelling that of like kind. The two electricities thus become accumulated on the two plates just as in Epinus's condenser (437), but there is no divergence of the leaves, for the opposite electricities counteract each other. The finger is now removed, and then the source of electricity, and still there is no divergence; but if the upper plate be now raised (fig. 420) the neutralisation ceases, and the electricity, being free to move, diffuses itself over the rod and the leaves, which then diverge widely. The delicacy of the apparatus is increased by adapting to the foot of the apparatus two metal rods, which are in conducting communication with the earth, terminating in knobs; for these knobs, being excited by induction from the gold leaves, react upon them, and attracting them, increase their divergence.

CHAPTER V.

VARIOUS EFFECTS OF ACCUMULATED ELECTRICITY.

443. **Effects of the electric discharge.**—The recombination of the two electricities, which constitutes the electrical discharge, may be either continuous or sudden; *continuous*, or of the nature of a current, as when the two conductors of a cylinder machine are joined by a chain or a wire; and *sudden*, as when the opposite electricities accumulate on the surface of two adjacent conductors, till their mutual attraction is strong enough to overcome the intervening resistances, whatever they may be. But the difference between a sudden and a continuous discharge is one of degree and not of kind, for there is no such thing as an absolute nonconductor, and the very best conductors, the metals, offer an appreciable resistance to the passage of electricity. Still, the difference at the two extremes of the scale is sufficiently great to give rise to a wide range of phenomena.

The phenomena of the discharge are usually divided into the *physiological*, *luminous*, *heating*, *mechanical*, *magnetic*, and *chemical* effects.

444. **Physiological effects.**—The physiological effects are those produced on living beings, or on those recently deprived of life. In the first case they consist of a violent excitement which electricity exerts on the sensibility and contractibility of the organic tissues through which it passes; and in the latter, of violent muscular convulsions which resemble a return to life.

The shock from the electrical machine has been already noticed (427). The shock taken from a charged Leyden jar, by grasping the outer coating with one hand and touching the inner with the other, is much more violent, and has a peculiar character. With a small jar the shock is felt in the elbow; with a jar of about a quart capacity it is felt across the chest, and with jars of still larger dimensions in the stomach.

A shock may be given to a larger number of persons simultaneously by means of the Leyden jar. For this purpose they must

form a chain by joining hands (fig. 421). If then the first touches the outside coating of a charged jar, while the last at the same time touches the knob, all receive a simultaneous shock, the intensity of which depends on the charge, and on the number of persons receiving it. Those in the centre of the chain are found to receive a less violent shock than those near the extremities. The Abbé Nollet discharged a Leyden jar through an entire regiment

Fig. 421.

of 1,500 men, all of whom received a violent shock in the arms and shoulders.

With large Leyden jars and batteries the shock is sometimes very dangerous. Priestley killed rats with batteries of 7 feet coated surface, and cats with a battery of about 4½ square yards coating.

445. **Luminous effects. Luminous jar.**—The luminous effects of electricity are in all cases due to the combination of the positive and negative electricities. Some of these effects have already

been made known in describing ***the electrical egg*** and ***the magic pane.*** We here give a description of another one.

The *luminous jar* (fig. 422) is a Leyden jar whose outer coating consists of a layer of varnish strewed over with metallic powder. A strip of tin foil on the bottom is connected with the ground by means of a chain ; a second band at the upper part of the coating has a projecting part, and the rod of the bottle is curved so that

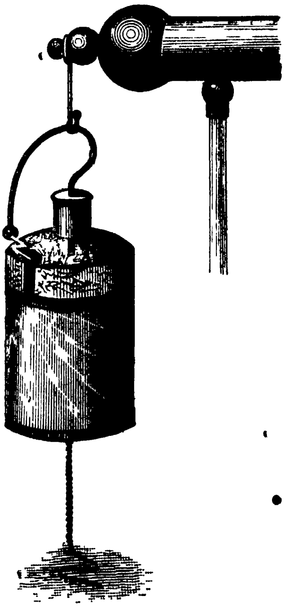


Fig 422.

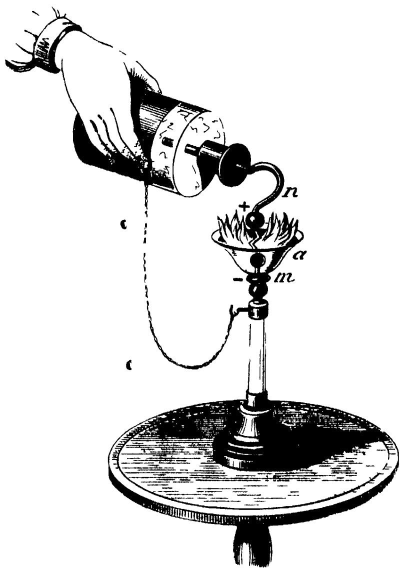


Fig. 423

the knob is about $\frac{1}{4}$ of an inch distant from the projection. This bottle is suspended from the machine, and as rapidly as this is worked large and brilliant sparks pass between the knob and the outer coating, illuminating the outside of the apparatus.

446. **Heating effects.**—Besides being luminous, the electric spark is a source of intense heat. When it passes through inflammable liquids, such as ether or alcohol, it ignites them. An arrangement for effecting this is represented in fig. 423. It is a small glass cup, through the bottom of which passes a metal rod,

terminating in a knob and fixed to a metal foot. A quantity of liquid sufficient to cover the knob is placed in the vessel. The outer coating of the jar having been connected with the foot by means of a chain, the spark which passes when the two knobs are brought near each other inflames the liquid. With ether or bisulphide of carbon, the experiment succeeds very well, but alcohol requires to be first warmed.

Coal gas may also be ignited by means of the electric spark. A person standing on an insulated stool places one hand on the

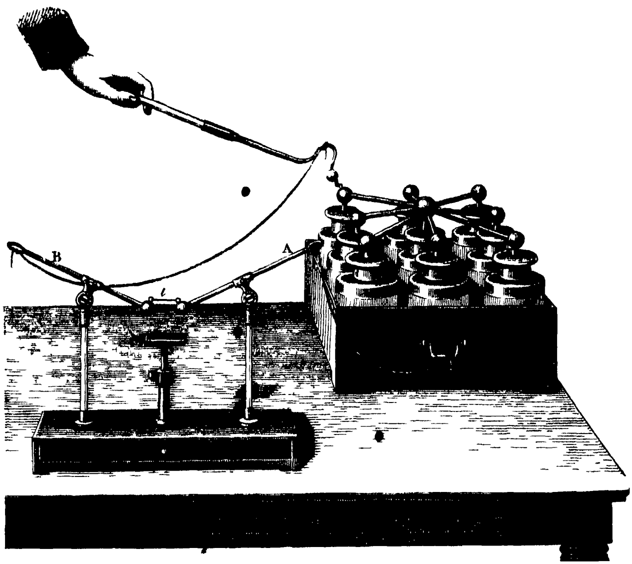


Fig. 424.

conductor of a machine which is then worked while he presents the other to the jet of gas issuing from a metallic burner. The spark which passes ignites the gas. This experiment may be curiously varied by igniting the gas by means of a piece of ice held in the hand.

When a battery is discharged through a metal wire it becomes incandescent, and may be melted or even volatilised, provided the charge be sufficiently powerful.

For this experiment an apparatus is used which is called *Henley's*

or *the universal discharger*, for it may be employed in a host of experiments on the electrical discharge. It consists (fig. 424) of two brass rods, A and B, each insulated on a glass stem. These rods can slide along hinged joints, so that they can be adjusted at any distance from each other and inclined in any direction. Between them is a small table support, which can be placed at any height, and which is intended to support objects which are to be submitted to the action of the discharge.

To melt a metal wire it is fixed at *i* to two knobs fastened on the rods, then connecting one of these by means of a chain with the outside of a powerful battery, the other is brought in contact with the inner coating, either by means of the discharging rod or by a chain attached to a metal rod fixed on a glass handle. The moment the spark passes between the knob and the battery, the wire, if it is fine enough, is melted in incandescent globules, and is

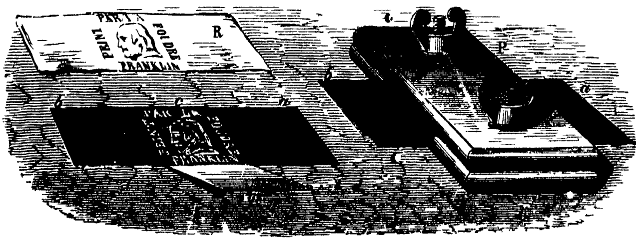


Fig 425.

even volatilised, that is, converted into vapour which disappears in the atmosphere. If the wire is thicker it simply becomes red hot but does not melt, and if still larger it is merely heated without becoming luminous.

When an electric discharge is sent through gunpowder placed on the table of a Henley's discharger, it is not ignited, but is scattered in all directions. But if a wet string be interposed in the circuit, a spark passes which ignites the powder. This arises from the retardation which electricity experiences in traversing a semiconductor, such as a wet string; for the heating effect is proportional to the duration of the discharge.

447. **Electrical portraits.**—The volatilisation of metals by the electrical discharge is applied to make what are called *electrical portraits.* For this purpose a thin card is taken of the shape *abm*

(fig. 425), and the design to be copied is cut out: a sheet of tinfoil is fastened on the rest of the card at *a* and *b*, but not at *c*. A leaf of gold is then placed upon the design, care being taken that it touches both the pieces of tinfoil, *a* and *b*. The lateral portion of the card, *m*, is then bent over, the card placed on a silk ribbon, and the whole pressed in a frame, P. When the discharge is passed

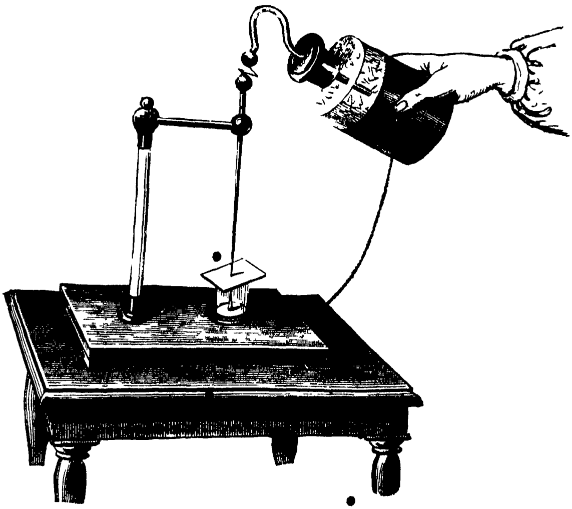


Fig. 426

from *a* to *b*, the tinfoil being thicker is not melted; but the gold, which is very thin, is volatilised, and forms on the ribbon through the pattern a brown coating, which reproduces all the details as seen in R.

448. **Mechanical effects.**—The mechanical effects are the violent lacerations, fractures, and sudden expansions which ensue when a powerful discharge is passed through a badly conducting substance. Glass is perforated, wood and stones are fractured, and gases and liquids are violently disturbed. The mechanical effects of electricity may be demonstrated by a variety of experiments. The body to be submitted to experiment is placed on the table, M (fig. 424), in contact with the two knobs which terminate the rods, A and B, so that they cannot receive the discharge without transmitting it

through the object on the table. Thus, for instance, if a piece of wood is placed so as to be struck in the direction of the fibres, it is smashed into pieces the moment the discharge passes.

Fig. 426 represents an arrangement for perforating a piece of glass or card. It consists of two glass columns, with a horizontal cross piece, in which is a pointed conductor. The piece of glass is placed on an insulating glass support, in which is placed a second conductor terminating also in a point, which is connected with the outside of the battery, while the knob of the inner coating is brought near the other knob. When the discharge passes between the two conductors the glass is perforated. The experiment only succeeds with a single jar when the glass is very thin; otherwise a battery must be used.

449. **Chemical effects.**—The chemical effects are the decompositions and recombinations effected by the passage of the electrical discharge. An instance of chemical combination brought about by the electric spark has been already given in the formation of water shown in fig. 409. Priestley found that when a series of electric sparks was passed through moist air, contained in a bent tube over mercury (fig. 427), its volume diminished, and blue litmus introduced into the vessel was reddened. This, Cavendish found, was due to the formation of nitric acid.

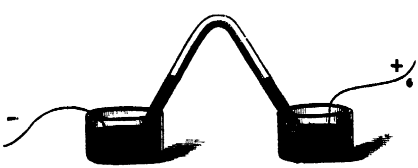


Fig. 427.

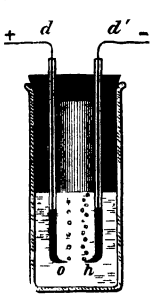


Fig. 428.

Water may conversely be decomposed by electrical sparks. This is best effected by means of what are called *Wollaston's points*, which consist of fine platinum wires fused into capillary tubes, and filed away so that only the section of the wire is presented to the liquid. One of such points placed in water (fig. 428) is connected by means of mercury in the tube, and the wire *d*, with the conductor of an electrical machine which yields positive electricity, while another point is connected with the ground by the wire *d'*; on working the machine so that sparks of about a millimetre strike across, it will be found that minute bubbles of oxygen gas are given off at the point at which the positive electricity enters, or the

positive pole, while about twice the quantity of hydrogen gas is given off at the negative pole. If the experiment be made with solution of copper sulphate, oxygen is still given off at the positive pole, while the negative becomes coated with metallic copper.

Decomposition of salts may also be easily shown by Faraday's experiment (fig. 429), which consists in placing discs of bibulous paper, B and D, soaked with solution of the salt in question. Connection is established between the discs, and with the prime conductor C on the one hand, and the earth on the other, by means of fine platinum wire. If the solution is one of a neutral salt, sulphate of soda for example, this is decomposed when the machine is worked, and free acid, recognisable by its action on litmus, is liberated at B, while D indicates the presence of free alkali.

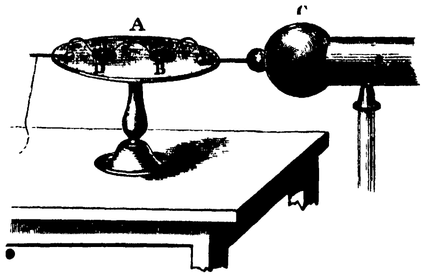


Fig. 429.

Among the chemical effects must be enumerated the formation of *ozone*, which is recognised by its peculiar odour and by its chemical properties, which are like those of oxygen, but far more energetic. The odour is perceived when an electrical machine is at work and electricity issues through a series of points from a conductor into the air. It has been ascertained to be an allotropic modification of oxygen which has properties the same in kind as those of oxygen, though much more powerful in degree.

450. **Magnetic effects.**—By the discharge of a large Leyden jar or battery, a steel wire may be magnetised if it is laid at right angles to the conducting wire through which the discharge is passed, either in contact with the wire or at some slight distance. And even with less powerful discharges a steel bar or needle may be magnetised by placing it inside a spiral of fine insulated copper wire (fig. 430). On passing the discharge through this wire the needle becomes magnetised. If the wire is coiled round the needle in the same direction as that in which the hands of a watch move, the south pole is at that end at which the positive electricity enters. If, on the contrary, the wire is coiled in the

opposite direction to the hands of a watch, the north pole is at the end at which the positive electricity enters.

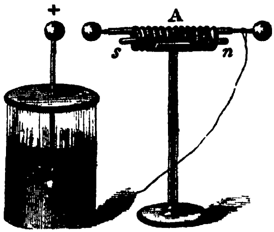


Fig. 430.

The most convenient way, perhaps of remembering the polarity produced, is to consider a person moving along the insulated wire in the direction of the positive electricity, and looking at the core the north pole is then always on his left hand.

This experiment is very interesting as being, perhaps, the best way of showing that the effects of the discharge of the Leyden jar are identical with those produced by the current.

CHAPTER VI

ATMOSPHERIC ELECTRICITY. THUNDER AND LIGHTNING.

451. **Thunder and lightning the effect of electricity.**—The first physicists who observed the zigzag motion of the electric spark compared it to the gleam of lightning, and its crackling to the sound of thunder. But Franklin, by the aid of powerful electrical batteries, was the first to establish a complete parallelism between lightning and electricity; and, in a memoir published in 1749, he pointed out the experiments necessary to attract electricity from the clouds by means of pointed rods. The electric fluid, said he, in concluding his memoir, is attracted by points; we know not whether lightning is endowed with the same property; but since electricity and lightning agree in all other respects, it is probable they will not differ in this; and *the experiment should be made.* The experiment was tried by Dalibard in France: and Franklin, pending the erection of a pointed rod on a spire in Philadelphia, had the happy idea of flying a kite, provided with a metal point, which could reach the higher regions of the atmosphere. In June 1752, during stormy weather, he flew the kite in a field near Philadelphia. The kite was flown with ordinary pack-thread, at the end of which Franklin attached a key, and to the key a silk cord, in order to insulate the apparatus; he then fixed the silk cord to a tree, and having presented his hand to the key, at first he obtained no spark. He was beginning to despair of success, when, rain having fallen, the cord became a good conductor, and a spark passed. Franklin, in his letters, describes his emotion on witnessing the success of the experiment as being so great that he could not refrain from tears.

Franklin, who had discovered the property of points (421), but who did not understand its explanation, imagined that the kite withdrew from the clouds its electricity; it is, in fact, a simple case of induction, and depends on the inductive action which the thunder-cloud exerts upon the kite and the cord.

452. **Atmospheric electricity.**—In order to ascertain the presence of electricity in the atmosphere, many forms of apparatus

have been used. To observe the electricity in fine weather, when its quantity is generally small, an electrometer may be used, as devised by Saussure for this kind of investigation. It is an electroscope similar to that already described, but the rod to which the gold-leaves are fixed is surrounded by a conductor two feet in length, and terminating either in a knob or a point. To protect the apparatus against rain, it is covered with a metal shield, four inches in diameter. The glass case is square instead of being round, and a divided scale on its inside face indicates the divergence of the gold-leaves.

To ascertain the electricity of the atmosphere, Saussure also used a copper ball, which he projected vertically with his hand. This ball was fixed to one end of a metal wire, the other end of which was attached to a ring, which could glide along the conductor of the electrometer. From the divergence of the gold-leaves the electrical condition of the air at the height which the ball had attained could be determined. Becquerel, in experiments made on Mont St. Bernard, improved Saussure's apparatus by substituting for the knob an arrow, which was projected into the atmosphere by means of a bow. A gilt silk thread, eighty-eight yards long, was fixed with one end to the arrow, while the other was attached to the stem of an electroscope.

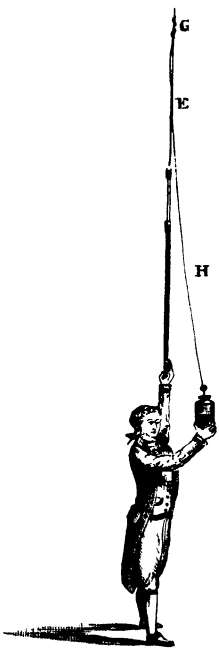


Fig. 431.

Volta charged a small Leyden jar with the electricity in the air by an arrangement represented in fig. 431. An ordinary rod is held in the hand, provided at one end with a brass ferrule in which fits a glass rod ; this in turn is provided with a ferrule in which is fixed a pointed metal rod, E. At the end of this is a cotton wick, G, soaked in spirits of wine. A wire, H, connects the wick to the inner coating of a small Leyden jar, the outer coating of which is held in the hand. Instead of the Leyden jar a small electroscope may be used with this arrangement.

Sometimes also kites are used, provided with a point, and con-

nected by means of a gilt cord with an electrometer. Captive balloons are likewise similarly used.

A good collector of atmospheric electricity consists of a fishing rod with an insulating handle, which projects from an upper window. At the top is a bit of lighted tinder held in metal forceps, the smoke of which, being an excellent conductor, conveys the electricity of the air down an insulated wire attached to the rod. A sponge moistened with alcohol, and set on fire, is also an excellent conductor.

453. **Ordinary electricity of the atmosphere.**—By means of the different apparatus which have been described, it has been found that the presence of electricity in the atmosphere is not confined to stormy weather, but that the atmosphere always contains free electricity, generally positive though occasionally negative. When the sky is cloudless, the electricity is always positive, but it varies in intensity with the height of the locality, and with the time of day. The intensity is greatest in the highest and most isolated places. No trace of positive electricity is found in houses, streets, or under trees ; in towns, positive electricity is most perceptible in large open spaces, on quays, or on bridges. In all cases, positive electricity is only found at a certain height above the ground. On flat land it only becomes perceptible at a height of five feet ; above that point it increases according to a law which is not made out, but which seems to be affected by the hygrometric state of the air.

When the sky is clouded, the electricity is sometimes positive and sometimes negative. It often happens that the electricity changes its sign several times in the course of the day, owing to the passage of an electrified cloud. During storms, and when it rains or snows, the atmosphere may be positively electrified one day, and negatively the next, and the numbers of the two sets of days are virtually equal. Atmospheric electricity is very abundant during fog, and is nearly always positive in fine weather. Its strength increases in general with the density of the fog.

The electricity of the ground has been found by Peltier to be always negative, but to different extents, according to the hygrometric state and temperature of the air.

Many hypotheses have been propounded to explain the origin of the atmospheric electricity. Some have ascribed it to the friction of the air against the ground, some to the growth of plants, or to the evaporation of water. Some, again, have compared the earth to a vast voltaic pile, and others to a thermo-electrical apparatus.

Several causes may, in fact, concur in producing the phenomena, and it must be admitted that at present we are unable to give any satisfactory explanation.

454. **Lightning.**—This, as is well known, is the dazzling light emitted by the electric spark when it shoots from clouds charged with electricity. In the lower regions of the atmosphere the light is white, but in the higher regions, where the air is more rarefied, it takes a violet tint; as does the spark of the electrical machine in a rarefied medium (432).

The flashes of lightning are sometimes several miles in length; they generally pass through the atmosphere in a zigzag direction; a phenomenon ascribed to the resistance offered by the air condensed by the passage of a strong discharge. The spark then diverges from a right line, and takes the direction of least resistance. In vacuo, electricity passes in a straight line.

Several kinds of lightning flashes may be distinguished:

1. The *zigzag* flashes, which move with extreme velocity in the form of a line of fire with sharp outlines, and which closely resemble the spark of an electrical machine.

2. The flashes which, instead of being linear, like the preceding, fill the entire horizon without having any distinct shape. This kind, which is most frequent, appears to be produced in the cloud itself, and to illuminate the mass. Another kind is called *heat* or *sheet* or *summer lightning*, because it illuminates the summer nights without the presence of any clouds above the horizon, and without producing any sound. The most probable of the many hypotheses which have been proposed to account for its origin is that which supposed it to consist of ordinary lightning flashes, which strike across the clouds at such distances that the rolling of thunder is so enfeebled as not to affect the ear of the observer.

Thus Luke Howard observed at Tottenham, while the sky was perfectly clear, abundant sheet lightning in a south-easterly direction, and afterwards learnt that there had been at the same time a violent thunder-storm between Dunkirk and Calais, a distance of over 100 miles.

Lightning is visible at a distance of 150 miles, while thunder is not heard at a greater distance than 27 miles.

There are, further, the rarer phenomenon of lightning flashes, which appear in the form of globes of fire, known also as *fireballs*. These, which are sometimes visible for as much as ten seconds, descend from the clouds to the earth with such slowness that the

eye can follow them. They often rebound on reaching the ground; at other times they burst and explode with a noise like that of the report of many cannon. This is sometimes known as *globe lightning*.

This is one of the most enigmatical phenomena in atmospheric electricity, seeing that no similar phenomena have been experimentally produced except accidentally.

The duration of the light of the first three kinds does not amount to the one hundred thousandth of a second, as has been determined by Wheatstone by means of a rotating wheel, which was turned so rapidly that the spokes were invisible; on illuminating it by the lightning flash, its duration was so short that, whatever the velocity of rotation of the wheel, it appeared quite stationary; that is, its displacement was not perceptible during the time the lightning existed.

The light produced by a lightning flash must be comparable to the sun in brightness, though it does not appear to us brighter than ordinary moonlight. But considering its excessively brief duration, and that the full effect of any light on the eye is only produced when its duration is at least the tenth of a second, it follows that a landscape continuously illuminated by the lightning flash would appear 100,000 times as bright as it actually appears to us during the flash.

455. **Thunder.**—*Thunder* is a violent report which succeeds lightning in stormy weather. The lightning and the thunder are always simultaneous, but an interval of several seconds is always observed between the perception of these two phenomena, which arises from the fact that sound only travels at the rate of about 1,100 feet in a second (165), while the passage of light is almost instantaneous. Hence an observer will only hear the noise of thunder five or six seconds, for instance, after the lightning, according as the distance of the thunder-cloud is five or six times 1,100 feet. The noise of thunder arises from the disturbance which the electric discharge produces in the air. Near the place where the lightning strikes, the sound is hard and of short duration. At a greater distance a series of reports are heard in rapid succession. At a still greater distance the noise, feeble at the commencement, changes into a prolonged rolling sound of varying intensity. Some attribute the noise of the rolling of thunder to the reflections of sound from the ground and from hills, clouds and buildings, which do not all reach the ear at the same time. Others have considered the lightning not as a single discharge, but as a series of dis-

charges, each of which gives rise to a particular sound. But as these partial discharges proceed from points at different distances, and from zones of unequal density, it follows not only that they reach the ear of the observer successively, but that they bring sounds of unequal density, which occasion the duration and inequality of the rolling. The phenomenon has finally been ascribed to the zigzags of lightning themselves, assuming that the air at each salient angle is at its greatest compression, which would produce the unequal intensity of the sound.

Thunder-clouds are usually flat at the bottom, while above are more or less dense masses of cloud piled up in peaks and hillocks. In reflected light such clouds are brilliantly white, but from their great density they transmit but little light, and hence when they are between us and the sun they seem dark grey or black.

456. **Effects of lightning.**—The lightning discharge is the electric discharge which strikes between a thunder-cloud and the earth. The latter, by the induction from the electricity of the cloud, becomes charged with contrary electricity; the electrified cloud and the earth are in a condition like the two coatings of a Leyden jar, and when the tendency of the two electricities to combine exceeds the resistance of the air, the spark passes, which is often expressed by saying that a 'thunderbolt has fallen.' Lightning in general strikes from above, but *ascending lightning* is also sometimes observed; possibly this is the case when the clouds being negatively, the earth is positively electrified, for experiments show that at the ordinary atmospheric pressure the positive electricity passes through the atmosphere more easily than negative electricity.

Fig. 432.

From the law of electric attraction (which is, that it is inversely as the square of the distance), the discharge ought to fall first on the nearest and best-conducting objects, and, in fact, trees, elevated buildings, metals, are more particularly struck by the discharge (fig. 433). Trees are good conductors from the sap they contain; hence it is imprudent to stand under or very near trees or shrubs during a thunderstorm.

The effects of lightning are very varied, and of the same kind as those of electrical batteries (441), but of far greater intensity. The lightning discharge kills men and animals, inflames combustible matter, melts metals, breaks bad conductors in pieces. When it penetrates the ground it melts the siliceous substances on its path, and thus often produces, in the direction of the discharge, those remarkable vitrified tubes called *fulgurites* (fig. 432), some of which are as much as twelve yards in length. When it strikes bars of iron, it magnetises them, and it often reverses the pole of compass needles.

After the passage of lightning, a highly peculiar odour is sometimes produced, like that perceived in a room in which an electrical machine is being worked. This odour is due to the formation of a peculiar oxygenised compound, to which the name *ozone* has been given; this, we have seen, is considered to be a peculiar allotropic modification of oxygen (449).

An electrified cloud forms with the earth below a condenser, the intervening mass of air being the dielectric (439). This mass of air is therefore in a state of strain like the dielectric in a Leyden jar, and it is to this state of strain which precedes the actual discharge, rather than to the discharge itself, that is due the production of ozone.

Rain water, too, collected after a thunderstorm contains on the average much more nitric acid than under ordinary circumstances. The production of nitric acid is, as we have seen (449), one of the effects of the electrical discharge through air.

Heated air conducts better than cold air, probably only owing to its lesser density. Hence it is that large numbers of animals, such as flocks of sheep, are often killed by a single discharge, as they crowd together in a storm, and a column of warm air rises from the group.

Many persons have an undue fear of the effects of the lightning discharge. This fear would be diminished if we remembered the very small number of persons who are really killed by lightning. Arago estimated the number for France at twenty in a year; that is, one victim for two million inhabitants; which is a far less proportion than that of many other accidents which do not excite nearly so much fear. The danger of death from a lightning discharge is far less than that from a railway accident.

457. **Return shock.**—This is a violent and sometimes fatal shock which men and animals experience, even when at a great

distance from the place where the lightning discharge passes. It is caused by the inductive action which the thunder-cloud exerts on bodies placed within the sphere of its activity. These bodies are then, like the earth, charged with the opposite electricity to that of the cloud ; but when the latter is discharged by the recombination of its electricity with that of the earth—thus when the discharge strikes a steeple (fig. 433)—the induction ceases, and the bodies, reverting rapidly from the electrical state to the neutral state, the concussion in question is produced, the *return shock.*

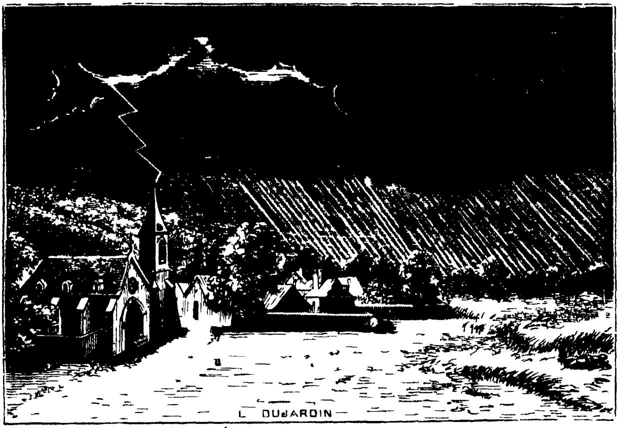


Fig. 433.

A more gradual decomposition and reunion of the electricity produces no visible effects ; yet it is not improbable that such disturbances of the electrical equilibrium are perceived by nervous persons.

The return shock is always less violent than the direct one ; there is no instance of its having produced any inflammation, yet plenty of cases in which it has killed both men and animals ; in such cases no broken limbs, wounds, or burns are observed.

The return shock may be imitated by placing a gold-leaf electroscope, the knob of which is connected by a wire with the ground, near the prime conductor of a powerful electrical machine in action ; the leaves diverge, but at each spark taken from the machine they suddenly collapse.

458. **Lightning conductor.**—The ordinary form of this instrument is an iron rod, through which passes the electricity of the ground attracted by the opposite electricity of the thunder-clouds. It was invented by Franklin in 1755.

There are two principal parts in a lightning conductor: the rod and the conductor. The *rod* (fig. 434) is a pointed bar of iron, fixed vertically to the roof of the edifice to be protected; it is from six to ten feet in height, and its basal section is about two or three inches in diameter. The conductor is a bar of iron which descends

Fig 434

from the bottom of the rod to the ground, which it penetrates to some distance. As iron rods cannot always be well adapted to the exterior of buildings in consequence of their rigidity, lightning conductors are formed of strands of wire, or wire rope, such as are used for rigging and for suspension bridges. The conductor is usually led into a well, and to connect it better with the soil it ends in two or three branches, or is connected with a large plate of metal or *earth plate*. If there is no well close at hand, a hole is dug in the soil to a depth of six or seven feet, or to a depth at

M M 2

which the ground is moist, and the plate of the conductor having been introduced, the earth is strongly rammed against it.

As the action of a lightning conductor depends on induction and the property of points (421), Franklin, as soon as he had established the identity of lightning and electricity, assumed that lightning conductors withdrew electricity from the clouds: the converse is the case. When a storm-cloud, positively electrified, for instance, rises in the atmosphere, it acts inductively on the earth, repels the positive and attracts the negative electricity, which accumulates in bodies placed on the surface of the soil the more abundantly as these bodies are at a greater height. The tension is then greater on the highest bodies, those, therefore, which are most exposed to the electric discharge; but if these bodies are provided with metal points, like the rods of conductors, the negative electricity, withdrawn from the ground by the influence of the cloud, flows into the atmosphere, and neutralises the positive electricity of the cloud. Hence, not only does a lightning conductor tend to prevent the accumulation of electricity on the surface of the earth, but it also tends to restore the clouds to their natural state, both which actions concur in preventing lightning discharges. This is indeed the manner in which the action of lightning conductors comes most frequently into play, though it is often overlooked; it is stated in reference to Pietermaritzburg, that until lightning rods became common in that town, it was constantly visited by thunderstorms at certain seasons. They come as frequently as ever, but cease to give flashes on reaching the town; they do so, however, when they have passed over it. The disengagement of electricity is, however, sometimes so abundant that the lightning conductor is inadequate to discharge the electricity, and the lightning strikes; but the conductor receives the discharge, in consequence of its greater conductivity, and the building is preserved.

It is stated that, approximately, a lightning conductor protects a circular space around it, the radius of which is double its height. Thus, a building, sixty-four yards in length, would be preserved by two rods eight yards in height, at a distance of thirty-two yards.

A lightning conductor should satisfy the following conditions: 1. The rod ought to be so large as not to be melted if the discharge passes; 2. It ought to terminate in a point, to give readier issue to the electricity disengaged by induction from the ground; 3. The conductor must be continuous from the point to the ground, and the connection between the rod and the ground must be as intimate

as possible; 4. If the building which is provided with a lightning conductor contains metallic surfaces of any extent, such as zinc roofs, metal gutters, or ironwork, these ought to be connected with the conductor. If the last two conditions are not fulfilled, there is a great danger of *lateral discharges*; that is to say, that the discharge takes place between the conductor and the edifice, and then it increases the danger.

A very simple, and at the same time efficient, lightning conductor may be easily fitted to any ordinary dwelling-house. It consists of a length of iron tubing an inch or more in diameter, which at the bottom is connected with the drains of the house, and projects above the highest point of the building, and which may, if desired, have a pointed rod attached to the top. By being connected with the drains it serves the useful purpose of ventilating them, while at the same time their moisture serves to establish a good connection with the earth.

Some electricians consider that ordinary No. 8 iron wire, connected suitably with a point projecting from the top of a building, and also with the earth, serves as an efficient protection for a building.

459. **Aurora borealis.**—The *aurora borealis*, or northern light, or more properly *polar aurora*, is a remarkable luminous phenomenon which is frequently seen in the atmosphere at the two terrestrial poles, but more especially at the north pole (fig. 435). At the close of the day an indistinct light appears in the horizon in the direction of the magnetic meridian. This luminosity gradually changes into a regular arc of a pale yellow, with its concave side turned towards the earth. Finally, the rays burst all over the horizon, passing necessarily from yellow to deep green, and to the most brilliant purple. All these rays converge towards one point of the horizon, which is in the prolongation of the line of the dipping needle, and they form then a fragment of an immense luminous cupola.

When the luminous arc is formed it often remains visible for some hours; then the lustre diminishes, the colours disappear, and this brilliant phenomenon gradually diminishes, or is suddenly extinguished.

Numerous hypotheses have been devised to account for the auroræ boreales. The constant direction of their arc as regards the magnetic meridian, and their action on the magnetic needle (405), suggest that they ought to be attributed to electric currents in the

higher regions of the atmosphere. This hypothesis is confirmed by the circumstance that during the prevalence of the aurora borealis, electric telegraph lines are spontaneously affected in a powerful but irregular manner; needles are deflected, armatures attracted, and alarums rung. This interference is at times so serious, especially in northern countries, that it is necessary to suspend the ordinary transmission of telegraphic messages. The discharges are in fact occasionally so steady and continuous as to form a true current of electricity, and cases are known in which the telegraphic

Fig. 435.

wires have been detached from the battery, and the discharge has been used instead.

According to De la Rive, the auroræ boreales are due to electric discharges which take place in polar regions between the positive electricity of the atmosphere and the negative electricity of the terrestrial globe; electricities which themselves are separated by the action of the sun, principally in the equatorial regions.

In Chapter XII. an experiment will be described which De la Rive devised in support of this hypothesis.

460. **St. Elmo's fire.**—This name is given by sailors to the luminous brushes or stars which sometimes appear at the tops of

masts and yards of vessels, and which are often accompanied by a crackling sound, resembling that heard when sparks are taken from electrical machines.

Similar effects are not unfrequently met with in the Alps on the travellers' umbrellas and alpenstocks.

These luminous effects were known to the ancients. Pliny speaks of the fiery stars seen on the ends of soldiers' lances. When they were two in number they were compared to Castor and Pollux, and that was a favourable presage; if only one appeared, it was likened to their sister Helena, which was considered to be a bad omen.

St. Elmo's fire is a simple case of induction. The atmospheric electricity acting on conductors decomposes the neutral fluid, attracting the contrary electricity, which, from the power of points, being liberated at the extremities of the masts, or by the metal of the lances, gives rise to the luminous brush. The same effect is observed when, placing a metal point on the conductor of the electrical machine, it is made to work in darkness.

461. **Atmospheric electricity on the Pyramids.**—Some curious observations were made by Siemens on the summit of the Cheops pyramid during the prevalence of the *kamsin* (297). On stretching his finger out a peculiar hissing sound was heard, and at the same time a prickly sensation was felt. On holding in one hand a filled champagne bottle, the cork of which was coated with tinfoil, the same sound was heard, and sparks continually passed from the label to the hand which held the flask, and when Siemens touched the top with the other hand he experienced a powerful shock.

In this case the liquid which was in conducting communication with the cork formed the inner coating of a Leyden jar, the outer coating of which was formed by the label and by the hand.

When the jar was improved by coating it with moistened paper, it gave such powerful discharges, with a striking distance of half an inch, that an Arab who held Siemens' hand was thrown to the ground as if struck by lightning, when Siemens presented the bottle to his nose.

CHAPTER VII.

ELECTRICITY DUE TO CHEMICAL ACTION. VOLTAIC BATTERY.

462. **Galvani's experiment.**—We have already seen that the two most powerful sources of electricity are friction and chemical combination. Having described the former, we are now to be concerned with the latter. Yet it may be premised that this is not a new kind of electricity, but only another method for its production far more abundant than friction, and leading to the most remarkable effects.

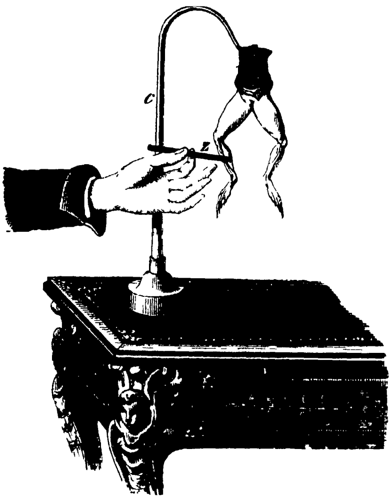


Fig. 436.

To Galvani, professor of anatomy in Bologna, is due the discovery in 1790 of these new electrical phenomena, to which he was led by a casual observation. It is said that a dead frog was accidentally suspended by a hook of copper to the iron railings of a balcony; it was observed to be violently contracted whenever the legs of the animal came in contact with the iron bars.

Galvani's observation may be reproduced in the following manner: the legs of a recently killed frog are prepared, and suspended to a copper hook, which passes between the vertebral column and the nerve filaments on each side of it. If then the copper support and the legs are momentarily connected by a plate of zinc, a smart contraction of the muscles ensues at each contact (fig. 436). Galvani had some time before observed that the electricity of machines produced in dead frogs analogous contractions, and

he attributed the phenomena first described to an electricity inherent in the animal. He assumed that this electricity, which he called *vital fluid*, passed from the nerves to the muscles by the metallic arc, and was thus the cause of contraction. This theory met with great support, especially among physiologists, but it was not without opponents. The most considerable of these was Alexander Volta, professor of physics in Pavia.

463. **Volta's fundamental experiment.**—Galvani's attention had been exclusively devoted to the nerves and muscles of the frog; Volta's was directed upon the connecting metal. Resting on the observation, which Galvani had also made, that the contraction is more energetic when the connecting arc is composed of two metals than when there is only one, Volta attributed to the metals the active part in the phenomenon of contraction. He assumed that the disengagement of electricity was due to their contact, and that the animal parts only officiated as conductors, and at the same time as a very sensitive electroscope.

By means of the then recently invented electroscope, Volta devised several modes of showing the disengagement of electricity on the contact of metals, of which the following is the easiest to perform:—

The moistened finger being placed on the upper plate of a condensing electroscope (fig. 419), the lower plate is touched with a plate of copper, *c*, soldered to a plate of zinc, *z*, which is held in the other hand. On breaking the connection and lifting the upper plate (fig. 420), the gold-leaves diverge, and, as may be proved, with negative electricity. Hence, when soldered together, the copper is charged with negative electricity, and the zinc with positive electricity. The electricity could not be due either to friction or pressure; for if the condenser plate, which is of copper, is touched with the zinc plate, *z*, the copper plate to which it is soldered being held in the hand, no trace of electricity is observed.

A memorable controversy arose between Galvani and Volta. The latter was led to give greater extension to his contact theory, and propounded the principle that when *two heterogeneous substances are placed in contact, one of them always assumes the positive and the other the negative electrical condition.* In this form Volta's theory obtained the assent of the principal philosophers of his time.

464. **Voltaic pile.**—Reasoning from this theory of contact, Volta was led in 1800 to the invention of the marvellous instrument which

electricities produced by each, Volta arranged, as represented in figure 437, a disc of zinc, a disc of copper, then a round piece of cloth moistened with acidulated water, then again a disc of zinc, a disc of copper, a piece of cloth, and so forth, care being taken always to preserve the same order. What was to be expected from such a combination? Arago says, 'I do not hesitate to assert that

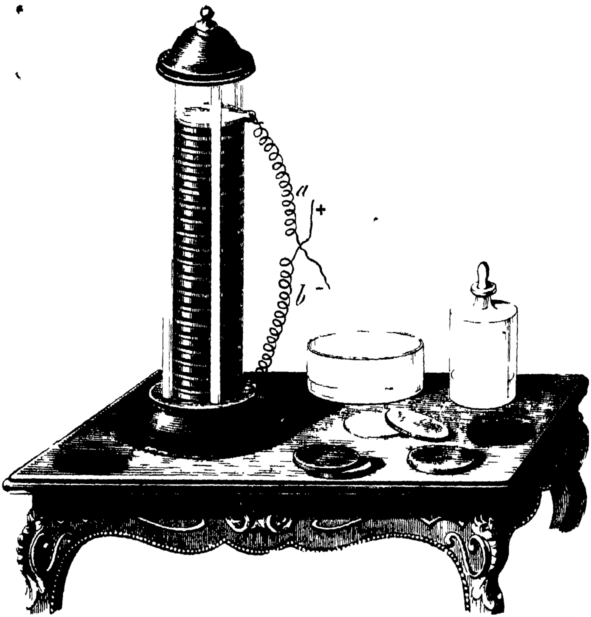


Fig. 437

this mass, so inert in appearance, this pile of so many couples of metal separated by a little liquid, is, as regards the singularity of its effects, the most remarkable instrument which has ever been invented, without even excepting the telescope and the steam-engine.'

On Volta's view the union of one zinc and one copper forms *a couple*; in the above figure twenty couples are superposed, separated from each other by pieces of cloth, and all arranged in the same order, so that one extremity terminates in a disc of copper, and the other in a disc of zinc. Since its invention it has been greatly

modified; but the general name of pile is still frequently used for all apparatus of the same kind, and the electricity thus furnished is spoken of as *voltaic or galvanic electricity* in honour of the discoverers.

465. **Disengagement of electricity in chemical action.**—The contact theory which Volta had propounded, and in which he explained the action of the pile, soon encountered objectors. Fabroni, a countryman of Volta, having observed that in the pile the discs of zinc became oxidised in contact with the acidulated water, thought that this oxidation was the principal cause of the disengagement of electricity. In England Wollaston soon advanced the same opinion, and Davy supported it by many ingenious experiments.

It is true that in the fundamental experiment of the contact theory (464) Volta obtained signs of electricity. But De la Rive showed that if the zinc be held in a wooden clamp all signs of electricity disappear, and that the same is the case if the zinc be placed in gases, such as hydrogen or nitrogen, which exert upon it no chemical action. De la Rive accordingly concluded that in Volta's original experiment the disengagement of electricity is due to the chemical actions which result from the perspiration and from the oxygen of the atmosphere. It must be admitted that the question as to the origin of electricity in the voltaic pile is still an open one.

By a variety of analogous experiments it may be shown that all cases of chemical action are accompanied by a disturbance of the electrical equilibrium. This is the case whether the substances concerned in the action are in the solid, liquid, or gaseous state, though of all chemical actions those between metals and liquids are the most productive of electricity. All the resultant effects may be explained on the general principle that when a liquid acts chemically on a metal the liquid assumes the *positive* electrical, and the metal the *negative* electrical, condition.

Hence we arrive at a theory of the origin of electricity in the voltaic pile which will be best illustrated by reference to the following simple experiment.

466. **Current electricity.**—When a plate of zinc and a plate of copper are partially immersed in dilute sulpheric acid, by means of delicate electroscopic arrangements it may be shown that the zinc plate possesses a feeble charge of negative and the copper plate a feeble charge of positive electricity. At the same time there is a slight disengagement of hydrogen gas from the surface of

the zinc. If now the plates be placed in direct contact, or, more conveniently, be connected by means of a metal wire, the chemical action increases, hydrogen is given off in larger quantities, but it is now disengaged from the surface of the copper (fig. 438) ; and if the connecting wire be examined it will be found to possess the remarkable properties characteristic of the discharge of opposite electricities ; the heating, the magnetic, the magnetising, the luminous effects. So long as the metals remain in the liquid, the opposite electrical conditions of the two plates discharge themselves by means of the wire, but are instantaneously restored, and as rapidly discharged ; and as these successive charges and discharges take place at such infinitely small intervals of time that they may be considered continuous, the wire is said to be traversed by an electric or voltaic *current.* The direction of this current *in the connecting wire* is assumed to be from the copper to the zinc, and in the liquid from zinc to copper ; or, in other words, this is the direction in which the positive electricity is supposed to flow, the direction of the negative current in the wire being from the zinc to the copper.

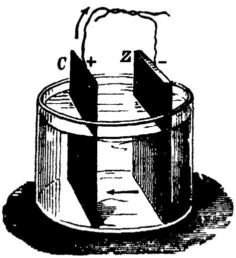


Fig. 438.

466 *a.* **Identity of frictional and voltaic electricity.**—In speaking of frictional and voltaic electricity, we must not be considered as implying that there is any essential distinction between them. There is only a difference in the mode in which electricity manifests itself. In the former we have effects of pressure, so that it is often called *statical* electricity ; in the latter we deal with the effects of a continuous flow, and thus we call it *dynamical* electricity. Frictional and voltaic electricity differ thus in degree and not in kind ; an electrical current may be regarded as a succession of electrical discharges, and conversely an electrical discharge may be regarded as a current of extremely short duration. All the effects which can be produced by frictional electricity can also be produced by dynamical electricity, and conversely all the effects which we shall afterwards describe as producible by voltaic electricity can likewise be produced by frictional electricity. The practical distinction between them is that just those effects which are most easily produced in the one way are most difficult to produce in the other. Thus, for instance, the simplest of all experiments in frictional electricity is that by which we demonstrate the existence of

an electrical state, the attraction of light bodies when a stick of sealing-wax is rubbed. The attraction of bodies can indeed be shown by voltaic electricity, but it requires the association of a great number of elements to produce even a very slight deflection in a delicately suspended pith ball. On the other hand, the deflection of a magnetic needle is, as we shall see, the simplest way of showing the existence of a voltaic current, and can be effected by the crudest apparatus. A magnetic needle can indeed be deflected by means of an electrical machine, but it requires special precautions, and a delicate galvanometer (486). The production of the electric spark is one of the simplest experiments; with a small electrical machine a spark of more than an inch in length is easily produced. To produce a spark of such a length De la Rue and Müller have found that no less than 11,000 cells arranged in a battery would be required.

467. **Voltaic couple. Electromotive series.**—The arrangement lately described, consisting of two metals in metallic contact and a conducting liquid in which they are placed, constitutes a *simple voltaic element* or *couple*. So long as the metals are not in contact, the couple is said to be *open*; when they are connected, either by being placed in direct contact or by the intervention of a conductor, it is said to be *closed*.

For the production of a voltaic current it is not necessary that one of the metals be unaffected by the liquid, although it is best so, but merely that the chemical action upon the one be greater than upon the other. The metal which is most attacked is called the *positive* or *generating* plate, and that which is least attacked the *negative* or *collecting* plate. The positive metal determines the direction of the current which proceeds *in* the liquid from the positive to the negative plate, and *out* of the liquid through the connecting wire from the negative to the positive plate.

In speaking of the direction of the current the positive current is always understood; to avoid confusion, the existence of the current in the opposite direction, the negative current, is tacitly ignored.

As a voltaic current is produced whenever two metals are placed in metallic contact in a liquid which acts more powerfully upon one than upon the other, there is great choice in the mode of producing such currents. In reference to their electrical deportment, the metals have been arranged in what is called an *electromotive series*, in which the most *electropositive* are at one end, and the most *electronegative* at the other. Hence when any two of these are

placed in contact in dilute acid, the current in the connecting wire proceeds from the one lower in the list to the one higher. The principal metals are as follows :—

1. Zinc.	4. Nickel.	7. Gold.
2. Lead.	5. Copper.	8. Platinum.
3. Iron.	6. Silver.	9. Graphite.

Thus iron placed in dilute sulphuric acid is electronegative towards zinc, but is electropositive towards copper ; copper in turn is electronegative towards iron and zinc, but is electropositive towards silver, platinum, or graphite.

The force produced by the difference in chemical action of two metals in a liquid is called the *electromotive force* ; it is greater in proportion to the distance of the two metals from one another in the series. That is to say, it is greater, the greater the difference between the chemical action upon the two metals immersed. Thus the electromotive force between zinc and platinum is greater than that between zinc and iron, or between zinc and copper.

468. **Poles and electrodes.**—If the wire connecting the two terminal plates of a voltaic couple be cut, it is clear, from what has been said about the origin and direction of the current, that positive electricity will be found at the end of the wire attached to the copper or negative plate, and negative electricity on the wire attached to the zinc or positive plate. These terminals have been called the *poles* of the battery. For experimental purposes, more especially in the decomposition of salts, plates of platinum are attached to the ends of the wires. Instead of the term poles, the word *electrode* (ἤλεκτρον and οδός, a way) is now commonly used, for these are the *ways* through which the respective electricities emerge. It is important not to confound the positive *plate* with the positive *pole* or *electrode*. The positive electrode is that connected with the negative plate, while the negative electrode is connected with the positive plate.

469. **Voltaic battery.**—When a series of voltaic elements or pairs are arranged in such a manner that the zinc of one element is connected with the copper of another, the zinc of this with the copper of another and so on, such an arrangement is called a *voltaic battery* ; and by its means the effects produced by a single element are capable of being very greatly increased.

The earliest of these arrangements was the voltaic pile devised by Volta himself (464).

It will be readily seen that it is merely a series of simple voltaic couples, the moistened disc acting as the liquid, and that the terminal zinc is the negative and the terminal copper the positive pole. From the mode of its arrangement, and from its discoverer, the apparatus is known as the *voltaic pile* (464), a term applied to all apparatus of this kind for accumulating the effects of dynamical electricity.

The distribution of electricity in the pile varies according as it is in connection with the ground by one of its extremities, or as it is insulated by being placed on a nonconducting cake of resin or glass.

In the former case, the end in contact with the ground is neutral, and the rest of the apparatus only contains one kind of

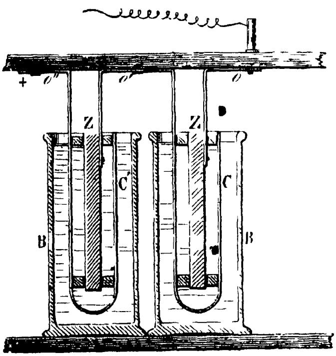


Fig. 439.

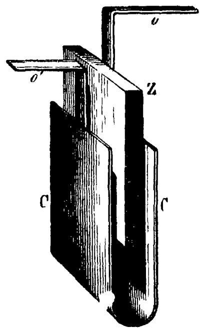


Fig. 440.

electricity; this is negative if a copper disc is in contact with the ground, and positive if it is a zinc disc.

If the pile be insulated the electricity is not uniformly distributed. By means of the proof-plane and the electroscope it may be demonstrated that the middle part is in a neutral state, and that one half is charged with positive and the other with negative electricity, the tension increasing from the middle to the ends. The half terminated by a zinc is charged with negative electricity, and that by a copper with positive electricity. The effects of the pile will be discussed in other places.

The original form of the voltaic pile, for it possesses now only an historical interest, has a great many inconveniences; among these is the fact that the weight of the discs of zinc and copper is

so great that it presses out the acidulated liquid from the discs, and the electrical action is soon weakened. It has received a great many improvements, the principal object of which has been to facilitate manipulation and to produce greater electromotive force (467), and to lessen the resistance.

One of the earliest of these modifications was the crown of cups, or *couronne des tasses*, invented by Volta himself; an improved form of this is known as *Wollaston's battery* (fig. 441).

Fig. 439 gives a vertical section of two consecutive Wollaston's elements. The acidulated water is contained in glass vessels, B B

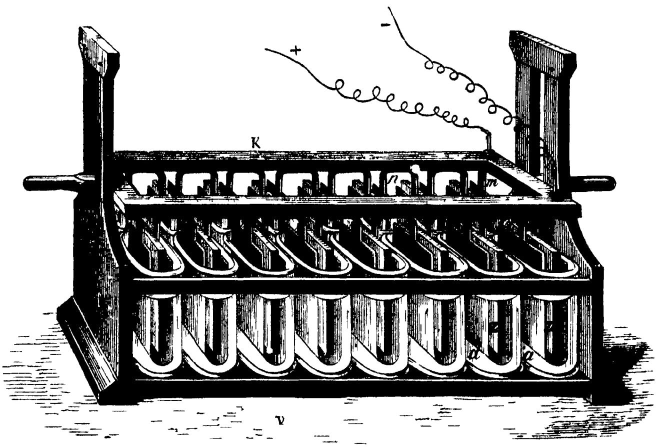


Fig. 441

in each of which is a couple. Fig. 440 represents the arrangement of one of these couples: it consists of a thick sheet of zinc and a strip of copper, *o*, by which it can be connected with the next couple. A plate of copper, C C, is bent so as to surround the plate of zinc without touching, contact being prevented by small pieces of cork. The plate, C, is provided with a copper tongue, *o'*, which is soldered to the zinc of the preceding couple, and so forth.

Fig. 441 represents a pile of sixteen couples united in two parallel series of eight each. All these couples are fixed to a cross frame of wood, by which they can be raised or lowered at pleasure.

When the battery is not wanted, the couples are lifted out of the liquid. The water in these vessels is usually acidulated with $\frac{1}{16}$ sulphuric and $\frac{1}{20}$ of nitric acid.

470. **Enfeeblement of the current in batteries. Secondary currents.**—The batteries already described, Volta's and Wollaston's, which consist essentially of two metals and one liquid, labour under the objection that the currents produced rapidly diminish in intensity.

This is principally due to three causes. The first is the decrease in the chemical action owing to the neutralisation of the sulphuric acid by its combination with the zinc. This is a necessary action, for upon it depends the current: it therefore occurs in all batteries, and is without remedy, except by replacement of acid and zinc. The second is due to what is called *local action*; that is, the production of small closed currents in the active metal, from the impurities it contains. These local currents rapidly wear away the active plate, without contributing anything to the general current. They are remedied by amalgamating the zinc with mercury, by which chemical action is almost entirely prevented except when the circuit is closed. The third arises from *secondary currents*. These are currents which are produced in the battery in a contrary direction to the principal current, and which destroy it either totally or partially. In the fundamental experiment (fig. 438), when the current is closed, sulphate of zinc is formed, which dissolves in the liquid, and at the same time a layer of hydrogen gas is deposited on the surface of the copper plate. This is called the *polarisation of the plate*. Now it has been found that the hydrogen deposited in this manner on metallic surfaces acts far more energetically than ordinary hydrogen. In virtue of this increased activity, it gradually reduces some of the sulphate of zinc formed, and a layer of metallic zinc is formed upon the copper; hence, instead of having two different metals unequally attacked, the two metals become gradually less different, and, consequently, in the wire there are two currents tending to become equal; the total effect, and the current really observed, become weaker and weaker.

471. **Constant elements.**—The serious objections to the use of what are called *single fluid* elements have led to their abandonment, and they are now generally replaced by *two fluid* elements, or those with two liquids, which are also called *constant* elements, because their action is without material alteration for a considerable period of time. The essential point to be attended

to in securing a constant current is to prevent the polarisation of the inactive metal; in other words, to hinder any permanent deposition of hydrogen on its surface. This is effected by placing the inactive metal in a liquid upon which the deposited hydrogen can act chemically.

472. **Daniell's element.**—This was the first form of the constant element, and was invented by Daniell in the year 1836. As regards the constancy of its action, it is still the best of all constant batteries. Fig. 442 represents a single element. A glass or porcelain vessel, V, contains a saturated solution of sulphate of copper, in which is immersed a copper cylinder, C, open at both ends, and perforated by holes. At the upper part of this cylinder there is an annular shelf, G, also perforated by small holes, and below the level of the solution: this is intended to support crystals of sulphate of copper to replace that decomposed as the electrical action proceeds. Inside the cylinder is a thin porous vessel, P, of unglazed earthenware. This contains either a solution of common salt or dilute sulphuric acid, in which is placed the cylinder of amalgamated zinc, Z. Two thin strips of copper, *p* and *n*, fixed by binding screws to the copper and to the zinc, serve for connecting the elements in series.

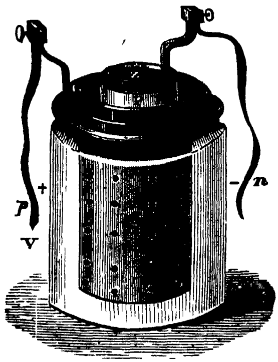


Fig. 442.

When a Daniell's element is closed, the hydrogen resulting from the action of the dilute acid on the zinc is liberated on the surface of the copper plate, but meets there the sulphate of copper, which is reduced, forming sulphuric acid and metallic copper, which is deposited on the surface of the copper plate. In this way the sulphate of copper in the solution is taken up, and, if it were all consumed, hydrogen would be deposited on the copper, and the current would lose its constancy. This is prevented by the crystals of sulphate of copper, which keep the solution saturated. The sulphuric acid produced by the decomposition of the sulphate permeates the porous cylinder, and tends to replace the acid used up by its action on the zinc; and as the quantity of sulphuric acid formed in the solution of sulphate of copper is regular and proportional to the

acid used in dissolving the zinc, the action of this acid on the zinc is regular also, and thus a constant current is produced.

Fig. 443 represents a series of three Daniell's elements of a somewhat different pattern. Here the zinc of one is connected with the copper of the next by a copper strip. Instead of placing the crystals of sulphate of copper on a shelf in the copper plate, they are contained in glass flasks, B, the necks of which are immersed in the solution of sulphate of copper. This form of element has been much used in the French telegraphs.

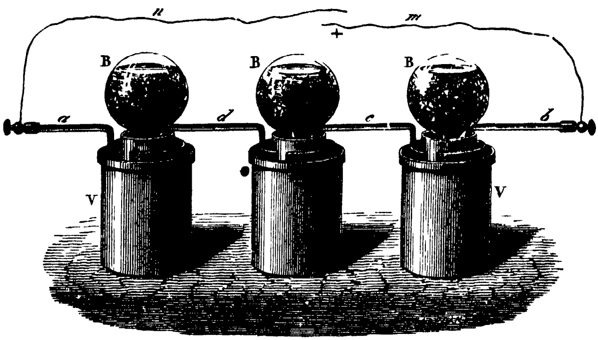


Fig. 443.

473. **Bunsen's element.**—*Bunsen's element*, also known as the *zinc-carbon* element, was invented in 1843 ; it is in effect a Daniell's element, in which nitric acid is substituted for solution of sulphate of copper, and in which copper is replaced by a cylinder of carbon. This is made either of the *graphitoidal carbon* deposited in gas retorts, known as *gas graphite*, or by calcining in an iron mould an intimate mixture of coke and bituminous coal, finely powdered and strongly compressed. Both these modifications of carbon are good conductors. Each element consists of the following parts : 1, a vessel, F (fig. 444), either of stoneware or of glass, containing, as in Daniell's, dilute sulphuric acid ; 2, a hollow cylinder, Z, of amalgamated zinc ; 3, a porous vessel, V, in which is ordinary nitric acid ; 4, a cylinder of carbon, C, prepared in the above manner. In the vessel F the zinc is first placed, and in it the carbon as seen in P. To the carbon is fixed a binding screw, *m* (fig. 445), to which a copper wire is attached, forming the positive pole. The zinc is

provided with a similar binding screw, *n*, and wire, which is thus the negative pole.

In Bunsen's element the hydrogen resulting from the action is liberated on the surface of the carbon. This being surrounded by

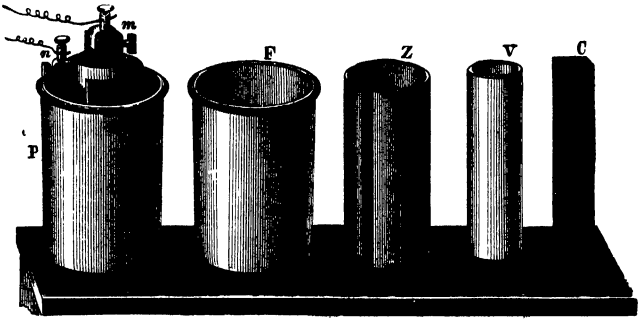


Fig. 444.

nitric acid, the hydrogen decomposes this acid, forming water and *hyponitrous acid*, which dissolves, or is subsequently disengaged as nitrous fumes. And, though the hydrogen is most completely got

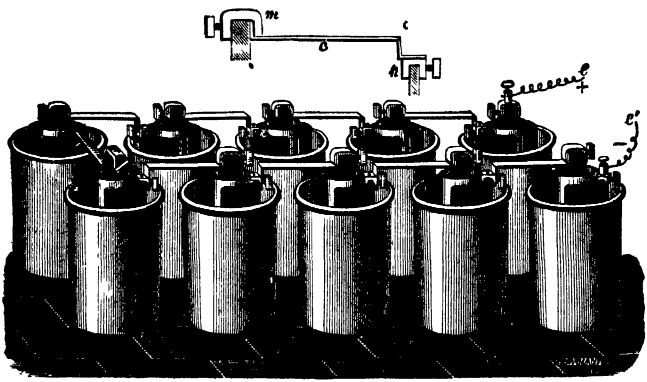


Fig. 445

rid of by the decomposition of the nitric acid, the production of these nitrous fumes is very noxious. These fumes may, however, be almost completely got rid of by adding to the vessel containing the nitric acid a small quantity of powdered potassium bichromate.

The elements are arranged to form a battery (fig. 445) by connecting each carbon to the zinc of the following one by means of the clamps, *mn*, and a strip of copper, *c*, represented in the top of the figure. The copper is pressed at one end between the carbon and the clamp, and at the other it is soldered to the clamp *n*, which is fitted on the zinc of the following element, and so forth. The clamp of the first carbon and that of the last zinc are alone provided with binding screws, to which are attached the wires.

Grove's element is constructed of zinc and platinum; zinc being placed in dilute sulphuric acid in an outer vessel, and the platinum in nitric acid in a flat porous pot. Like Bunsen's the element has great electromotive force; it has also a small internal resistance (488); it is more compact and convenient to manipulate than Bunsen's.

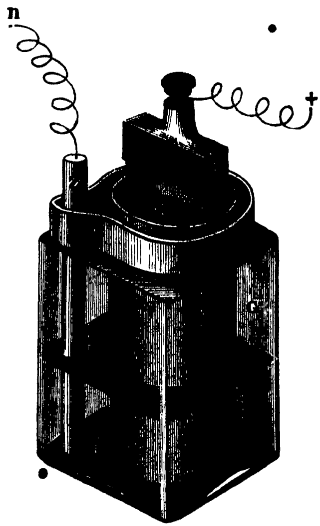


Fig. 446.

474. **Leclanché's element.** Each element (fig. 446) consists of a rod of carbon, L, placed in a porous pot, which is then tightly packed with a mixture of pyrolusite (peroxide of manganese) and coke, M. The porous pot is contained in an outer vessel, G, in which is the electropositive metal zinc, Z. The exciting liquid is a solution of sal-ammoniac. This battery, from its simplicity, its constancy, combined with considerable electromotive force, is now in extended use for telegraphs, and for alarums in private houses.

474*a*. **Minotto's element. Gravity battery.**—We may mention here two elements which are modifications of that of Daniell, and which are remarkable for the facility with which they are constructed. The object is to get rid of the porous pot, the use of which is attended with numerous drawbacks.

Minotto's element (fig. 447) consists of a glass or earthenware vessel at the bottom of which is a copper disc, to which is rivetted an insulated copper wire. This is surrounded by a thick layer of

crystals of sulphate of copper, and on this a paper disc is placed. Next comes a thick layer of sawdust, and on this rests a round zinc block, to which a wire is attached. To work the element, water is carefully added until the entire mass is thoroughly soaked. There is thus a solution of copper sulphate at the bottom, and one of water, to which a few drops of acid are added, at the top. When

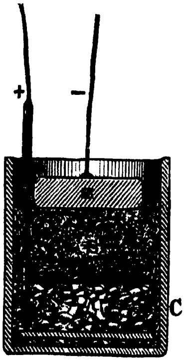


Fig. 447.

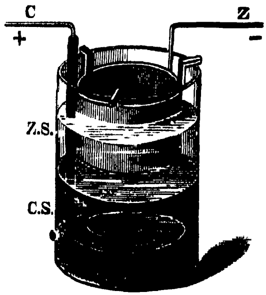


Fig. 448.

the element is closed by connecting the two wires, an action is set up which is analogous to that of the ordinary Daniell. For arrangement in battery the zinc block is cast on to the wire from the copper plate. This battery is largely used in India.

Another form is known as the *Gravity battery*, in which the porous diaphragm is altogether dispensed with. The form depicted in fig. 448 is that of Calland. The copper plate, provided with an insulating wire, is immersed in a saturated solution of sulphate of copper, while on the top of this a solution of zinc sulphate floats in consequence of its lower specific gravity. The zinc block rests by means of lugs on the top of the vessel. When the wires are connected action is at once set up.

Such elements as this cannot be moved about, for otherwise the liquids would mix, metallic copper would be deposited on the zinc plate and give rise to local action. They serve for heavy telegraph lines, and are largely used in France and in Austria.

CHAPTER VIII.

EFFECTS OF THE BATTERY.

475. **Physiological effects.**—The remarkable phenomena of the voltaic battery may be classed under the heads physiological, chemical, mechanical, and physical effects; and these latter may be

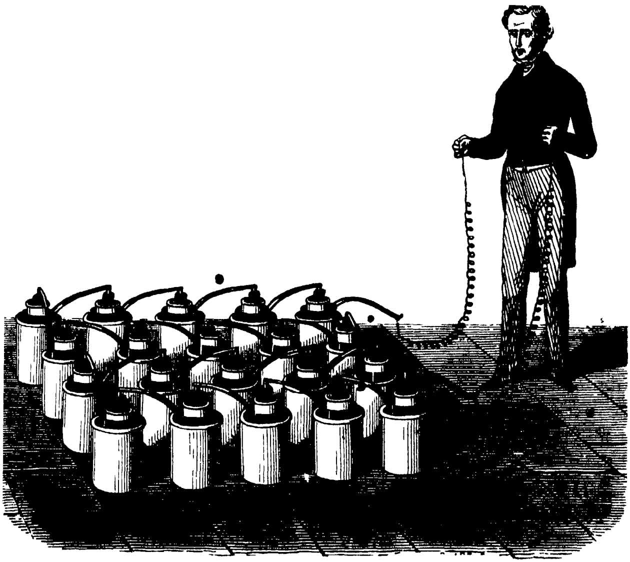


Fig. 449.

again subdivided into the thermal, luminous, and magnetic effects. All these effects are due to the recombination of the opposite electricities, like those of the electrical machine; but they are far more remarkable and more energetic, owing to the continuity of their action. To produce them the body experimented upon must be connected on the one side with the positive and on the other with the negative pole of the battery.

The *physiological effects* consist of shocks and violent contractions which the current produces in the muscles not only of living but of dead animals, as has been seen in Galvani's experiment with the frog.

When the electrodes of a powerful battery are held in the two hands a violent shock is felt, resembling that of a Leyden jar, especially if the hands are moistened with acidulated or saline water, which increases the conductivity. The shock is more violent in proportion to the number of elements used; with a Bunsen's battery of 50 to 60 couples, the shock is very strong, with 150 or 200 couples it is unbearable, and even dangerous when continued. It is less perceptible in the fore part of the arms than the shock of the Leyden jar, and when transmitted through a chain of several persons it is generally only felt by those nearest the poles.

The shock, as in the case of the Leyden jar, is due to the recomposition of the two electricities; with this difference, that with the Leyden jar, the discharge being instantaneous, the resultant shock is so also; while in the latter case, as the battery is immediately recharged after each discharge, the shocks succeed each other in rapidity.

A feeble current when opened and closed in the parts over the eye produces a luminous effect, in the neighbourhood of the ears a rushing sound; and when the two poles are placed on the tongue the positive has an acid and the negative an alkaline taste. This indeed is a convenient test for the conditions of a current. Sensitive plants are also affected when a battery consisting of a large number of elements is opened and closed in contact with them.

476. **Heating effects.**—When a voltaic current is passed through a metal wire the same effects are produced as by the discharge of an electric battery; the wire becomes heated and even incandescent if it is very short and thin. With a powerful battery all metals are melted, even iridium and platinum, the least fusible of metals. Carbon is the only body which hitherto has not been fused by it.

A battery of thirty to forty Bunsen's elements is sufficient to melt and volatilise fine wires of lead, tin, zinc, copper, gold, silver, iron, and even platinum, with differently coloured sparks. Iron and platinum burn with a brilliant white light; lead with a purple light; the light of tin and of gold is bluish white; the light of zinc is a mixture of white and gold; finally, copper and silver give a green light.

When a voltaic couple is closed, a certain amount of heat is produced, which is distributed over the whole circuit; the liquid, the

plates, and the connecting wire. The quantity of this heat depends on the consumption of the attacked metal, which is practically always zinc. The solution of a definite weight of zinc produces a definite quantity of heat; if this solution takes place rapidly, the temperature is higher than if it takes place slowly; but the total quantity in each case is the same, just as the total amount of heat produced by burning a given weight of coal (305) is the same whether it be burnt fast or slowly. Zinc, associated with platinum or carbon to form a voltaic element, produces more heat in a given time than if it is associated with copper; for the rate at which the zinc dissolves is greater in the former case. Hence the advantage of great electromotive force in elements where the heating effect is to be utilised.

Again, the distribution of heat in the voltaic circuit follows the simple law that the heat produced in any particular part of the circuit stands in the same ratio to the total heat, that the resistance (488) of that particular part bears to the total resistance. Thus if the resistance of the connecting wire, outside the cell, is twice as great as that of the liquid in the cell, the heat in the connecting wire will be twice that in the liquid, or two-thirds of the total heat.

The laws which express the relation between the heating effect in a voltaic circuit, and the strength of the current and resistance of its various parts, have been investigated by means of an apparatus called the *Galvanothermometer* (fig. 450). A wide-mouthed stoppered bottle is fixed upside down, with its stopper, *b*, in a wooden block; the stopper is perforated so as to give passage to two thick platinum wires, connected at one end with binding screws, *s s*, while their free ends are provided with platinum cones to which different wires under investigation could be affixed; the vessel contains alcohol, the temperature of which is

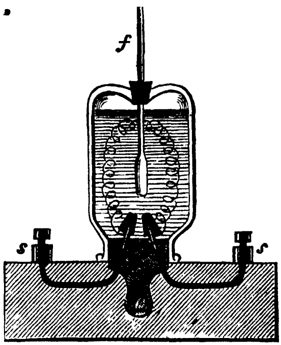


Fig. 450.

indicated by a thermometer. The current is passed through the platinum wires, and its strength measured by means of a tangent galvanometer (488) interposed in the circuit. By observing the

increase of temperature in the thermometer in a given time, and knowing the weight of the alcohol, the mass of the wire, the specific heat, and the calorimetric values (453) of the vessel, and of the thermometer, compared with alcohol, the heating effect which is produced by the current in a given time can be calculated.

If the current passes through a chain of platinum and silver wire of equal sizes, the platinum becomes more heated than the silver from its greater resistance; and with a suitable current the platinum may become incandescent while the silver remains dark. This experiment was devised by Children.

476*a*. **Applications of the heating effect.**—The heating effects of the voltaic current are used in firing mines for military purposes and for blasting operations. A simple form of fuse for this purpose is shown in fig. 451, which represents a round piece of wood about half an inch in diameter in which two grooves are cut. Two copper wires, *a a* and *b b*, insulated except at the free ends, fit in these grooves and pass through holes bored in the wood without touching each other, and are kept in their place by being wrapped round with fine thread. The ends bared are connected by a thin platinum wire *ab*, and the other ends of the wire are joined to stout copper wires which lead to the neighbourhood of the battery. Round the fuse is wrapped a paper case (not represented in the figure) which is filled with fine powder, and, being closed, the fuse is then placed in a bag of powder in the place where the explosion is to take place. Now we have seen that in any part of a voltaic circuit the heating effect is the greater according as the *resistance* of that part of the circuit is greater. This is the reason for having a thin platinum wire, for the resistance is greater the thinner the wire, and platinum is a metal which offers great resistance. Accordingly, when the current of a few Grove's cells (473) is transmitted through the circuit, the thin platinum wire is instantaneously raised to incandescence and explodes the powder.

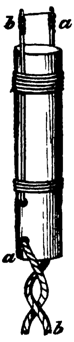


Fig. 451.

A useful application of the heating effect of the current is made in the surgical operation of *cauterisation.* If a carbuncle or other enlargement is to be removed, a thin platinum wire which forms part of a circuit is moved across it; this cuts like a knife, and at the same time cauterises the surface thus cut. It has been observed

that when the temperature of the wire is about 600° C., the combustion of the tissues is so complete that there is no hæmorrhage; while at 1500° the action of the wire is like that of a sharp knife.

Another application of the heating effect is to what are called *safety catches*. These are lengths of lead wire interposed in the circuit of the powerful currents used for electrical lighting and the

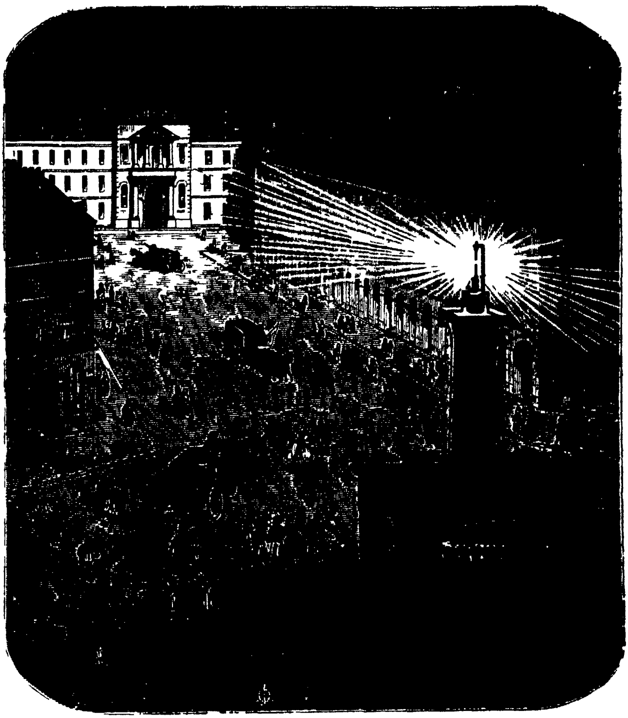


Fig. 452.

like. Their dimensions are so calculated that when the current attains a certain strength, the heat generated is sufficient to melt them, and thus break the continuity of the circuit. As this can be calculated and arranged with great accuracy, it is possible so to regulate the circuit that it shall not exceed a certain limit.

477. **Luminous effects.**—On closing a voltaic battery a spark is obtained at the point of contact which is frequently of great brilliance. A similar spark is also perceived on breaking contact. These luminous effects are obtained, when the battery is sufficiently powerful, by bringing the two electrodes very nearly in contact; a succession of bright sparks springs across the interval, which follow each other with such rapidity as to produce a continuous light. With eight or ten of Grove's elements brilliant luminous sparks are obtained by connecting one terminal of the battery with a file, and moving its point along the teeth of another file connected with the other terminal.

The most beautiful effect of the electric light is obtained when two pencils of charcoal are connected with the terminals of a powerful battery in the manner represented in fig. 452. The two charcoals being placed in contact, the current passes, and their ends soon become incandescent. If they are then removed to a distance of about the tenth of an inch, the air between them is heated, little particles become detached, are heated to incandescence, and travel from one carbon to the other: they thus form a luminous arc extending between the two points, which has an exceedingly brilliant lustre, and is called the *voltaic arc*.

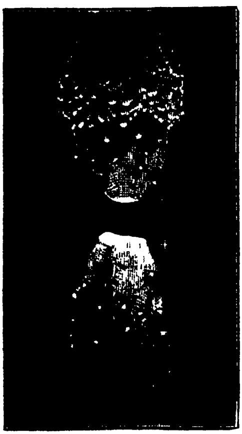


Fig. 453.

The length of this arc varies with the force of the current. In air, with a battery of 600 elements, it may exceed two inches. If the charcoal attached to the positive pole be examined, it will be found to have become worn away, forming a crater-like hollow, while the negative charcoal increases (fig. 453). It thus seems that the carbon is mechanically transported from the positive to the negative pole, and that this is the manner in which the transmission of the electricity between the two poles is effected. The small globules seen in the figure are from mineral impurities in the carbon, melted at the high temperature of the voltaic arc.

Fig. 452 represents an arrangement for public illumination. On a convenient support, an electric lamp is placed: this is a

mechanism which is worked by the current from a powerful battery, and which keeps the carbon poles at a suitable distance, a condition necessary for the permanence and steadiness of the light.

There are numerous and varied forms of such apparatus, and usually they are complicated and expensive: but a general idea of the way in which they act may be illustrated by reference to a much simpler apparatus devised by Browning. The current enters the lamp by a wire attached to a binding screw on the base of the instrument, passing up the pillar by the small electro-magnet to the centre pillar along the top of the horizontal bar, down the left-hand bar through the two carbons, and away by a wire attached to a binding screw on the left hand. A tube holding the upper carbon slides freely up and down a tube at the end of the cross-piece, and would by its own weight rest on the lower carbon, but the electro-magnet is provided with a keeper, to which is attached a rest that encircles the carbon tube and grasps it. When the electro-magnet works and attracts the keeper, the rest tightens, and thereby prevents the descent of the carbon. When the keeper is not attracted the rest loosens, and the carbon-holder descends.

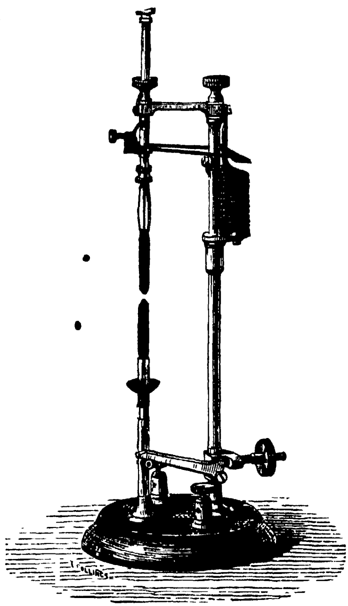


Fig. 454.

When the two carbons are at rest, on making contact with a battery, the current traverses both carbons and no light is produced. But if the upper carbon be raised ever so little, a brilliant light is emitted. When the lamp is thus once set to work, the rod attached to the upper carbon may be let go, and the magnet will afterwards keep the lamp at work. For when some of the carbon is consumed, and the interval between the two is too great for the current to pass, the magnet loses some of its power, the keeper loosens its hold on the carbon, and this

descends by its own weight. When they are sufficiently near, but before they are in contact, the current is re-established; the magnet again draws on the keeper, and the keeper again checks the descent of the carbon, and so forth. Thus the points are retained at the right distances apart, and the light is continuous and brilliant.

The lights thus produced are known as *arc lights*, and the apparatus in which they are produced are *arc lamps.*

The cost and inconvenience of producing electricity by means of the voltaic battery are so great as to quite preclude its use unless in very exceptional cases. But of late years great improvements have been effected in magneto-electrical machines, which transform mechanical power into electricity in a very perfect manner, and yield it at a price which makes the electric light a formidable competitor with gas, and other artificial lights for purposes of public and even of household illumination. The current from such machines is conveyed by wires to a lamp such as that represented in fig 455. These arc lights, however, are not readily subdivided without loss, and they are deficient in steadiness; they are best fitted for lighting large spaces, such as railway stations, docks, streets, and the like. What are called *incandescent lights*, though not so powerful, are best suited for indoor illumination, as the light is pleasanter and is distributed from a number of centres. The principle on which these depend is that of allowing the current to traverse a thin thread of specially prepared carbon enclosed in a glass vessel from which the air has been entirely exhausted. The ends of this carbon filament are suitably connected with wires, *a a′*, terminating in loops outside, which can be readily attached to the hooks *b b′*; these in turn are connected with binding screws, P N, with which the wires conveying the current are connected. By means of the screw, V, the support C with its lamp can be attached to an upright stand, or to a bracket, like a gaselier. Carbon is chosen because it is infusible, and non-volatile, which is not the case with any metal when traversed by a sufficiently powerful current. There are numerous

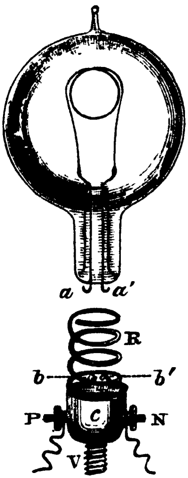


Fig. 455.

forms of such incandescent lamps; that represented in fig. 455 was devised by Swan of Newcastle, whose carbon thread is prepared by carbonising a special kind of cotton thread. Edison of New York uses bamboo in the construction of the carbon filament.

The filament in an incandescent lamp, after being in use for some time, becomes disintegrated and gives way; but a carefully constructed lamp will, with a moderate current, last for 1,000 hours. The intensity of the light depends upon and increases with the strength of the current; a lamp, for instance, which has an illuminating power of 16 candles (317) may have its luminosity doubled, or even more, by an increase in the strength of the current. This

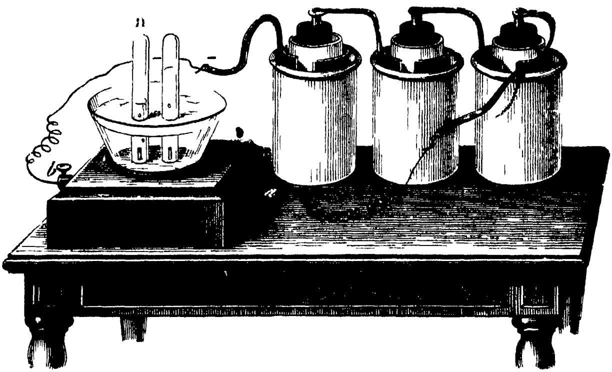


Fig 456.

increase in luminosity is, however, purchased at the expense of the duration of the lamp, the more powerful the current, and therefore the luminosity, the shorter time does the lamp last.

A horse-power (511*a*) employed in working the machine which produces the current will feed 12 lamps each of 16-candle power; the same current with an arc light will produce from five to ten times the illuminating power.

478. **Chemical effects. Decomposition of water.**—These are among the most important of all the actions of the voltaic circuit. They consist of the separation and transport of the elements of the bodies traversed by the current. The first decomposition effected by the battery was that of water, obtained in 1800 by Carlisle and Nicholson by means of a voltaic pile. Water is rapidly decomposed by three or four Bunsen's cells; the apparatus (fig. 456) is very

convenient for the purpose. It consists of a glass vessel fixed on a wooden base. In the bottom of the vessel two platinum electrodes are fitted, communicating by means of copper wires with the binding screws, *a* and *b*. The vessel is filled with water to which some sulphuric acid has been added to increase its conductivity, for pure water is a very imperfect conductor; two glass tubes filled with water are inverted over the electrodes, and, on interposing the apparatus in the circuit of the battery, decomposition is rapidly set up, and gas bubbles rise from the surface of each pole. The volume of gas liberated at the negative pole is about double that set free at the positive, and on examination the former gas is found to be

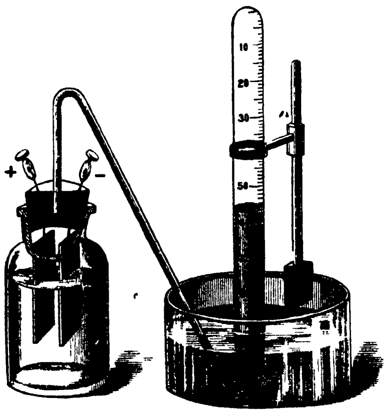


Fig. 457.

hydrogen and the latter gas oxygen. This experiment accordingly gives at once the qualitative and quantitative analysis of water, for it shows that it consists of two parts by volume of hydrogen to one part by volume of oxygen.

If the two platinum electrodes are placed close together in acidulated water, the gases can be collected mixed instead of separately. Such a mixture of the two gases explodes and re-forms water with great violence when a light is applied to it, or, when contained in a suitable vessel, an electric spark is passed through it; this mixed gas is known as *detonating gas*. If it be collected in a graduated glass tube, it is found that currents of different strengths

liberate the gas with varying rapidity; the more powerful the current, the more rapidly is the gas disengaged. The volume liberated in a given time is proportional to, and is therefore a measure of, the strength of the current; an apparatus based on this principle was devised by Faraday and called a *Voltameter* (fig. 457).

479. **Electrolysis.**—To those substances which, like water, are resolved into their elements by the voltaic current, the term *electrolyte* was applied by Faraday, to whom the principal discoveries in this subject, and also the nomenclature, are due; *electrolysis* is a decomposition produced by the voltaic battery.

By means of the battery, the compound nature of several substances which had previously been considered as elements has been determined. With a battery of 250 couples, Davy, shortly after the discovery of the decomposition of water, succeeded in decomposing the alkalies potass and soda, and proved that they were the hydrated oxides of the hitherto unknown metals *potassium* and *sodium*. The decomposition of potass may be demonstrated with the aid of the battery of four to six elements in the following manner: a small cavity is made in a piece of solid caustic potass, which is moistened, and a drop of mercury is placed in it (fig. 458). The potass is placed on a piece of platinum connected with the positive pole of the battery. The mercury is then touched with the negative pole. When the current passes, the potass is decomposed, oxygen is liberated at the positive pole, while the potassium liberated at the negative pole amalgamates with the mercury. On distilling this amalgam out of contact with air, the mercury passes over, leaving the potassium.

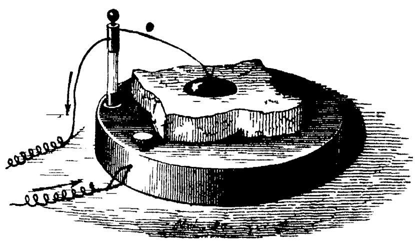


Fig. 458.

The decomposition of binary compounds, that is, bodies containing two elements, is quite analogous to that of water and potass; one of the elements goes to the positive, and the other to the negative pole. The bodies separated at the positive pole are called *electronegative* elements, because at the moment of separation they are considered to be charged with negative electricity, while those separated at the negative pole are called *electropositive* elements. One and the same body

may be electronegative or electropositive, according to the body with which it is associated. For instance, sulphur is electronegative towards hydrogen, but is electropositive towards oxygen. The various elements may be arranged in such a series that any one in combination is electronegative to any following, but electropositive towards all preceding ones. This is called the *electro-chemical series*, and begins with oxygen as the most electronegative element, ending with potassium as the most electropositive.

480. **Electrotype.**—In the ordinary methods of reproducing statues, bas-reliefs, etc., in metal, moulds of baked clay or of sand are prepared, which are faithful hollow copies of these objects; then either melted iron or bronze is run into these; when the metal has solidified an exact copy in relief is obtained of the object. In electrotypes, a mould of the object to be produced is required, but the reproduction is effected without either fusion or fire. The current of a battery quietly deposits a layer of metal of any desired

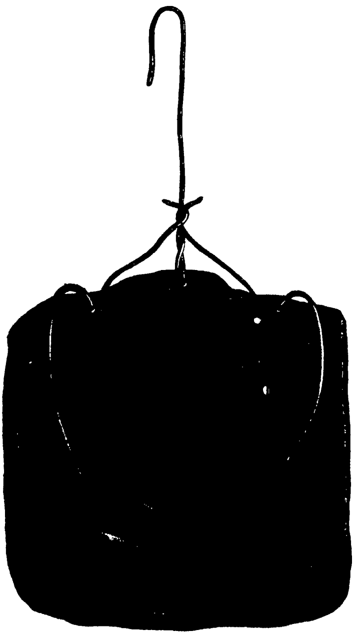


Fig. 459.

Fig. 460.

thickness on a faithful impression of the object. This is the meaning of the term *galvanoplastics*, which is derived from the word galvanism, and from a Greek word signifying 'to model.'

The practice of electrometallurgy consists of two distinct operations: firstly, the preparation of the mould or impression of the objects to be reproduced; and, secondly, the deposit of the metal in this mould. The first process is the most delicate, and that on which mainly depends the success of the operation.

Various substances are used for taking impressions, wax, stearine, fusible metal, gutta-percha, etc. Of these the most useful, at any rate for small objects, is gutta-percha. This substance, which is hard at ordinary temperatures, softens when placed in warm water. When it has acquired the proper degree of softness, a plate of it is placed on the object to be copied and pressed against it. When the object is of metal, a medal for instance, the gutta-percha is easily detached as soon as it is cold; but with a wood engraving or a plaster cast, the gutta-percha adheres, and cannot be detached without danger of tearing. This may be remedied by previously brushing the mould over with black lead, or *graphite*, as it ought to be called.

Suppose the subject to be reproduced is a medal (fig. 460); when the mould is obtained we have the medal hollow and inverted. It is now necessary to make its surface a conductor, for gutta-percha, being an insulator, could not transmit the current from the battery. This is effected by brushing it over very carefully with graphite (which is a good conductor) in all those places where the metal is to be deposited. Three copper wires are then fixed to it, one of which is merely a support, while the two others conduct the current to the metallic surface.

The mould is then ready for the metal to be deposited upon it; copper is ordinarily used, but silver and gold also deposit well.

In order to take a copper cast, a bath is filled with saturated solution of sulphate of copper, and two copper rods, B and A, are stretched across (fig. 461), one connected with the negative and the other with the positive pole of Grove's, or preferably, from its greater constancy, a Daniell's element. From the rod connected with the negative pole, B, is suspended the mould, and from the other, A, a plate of copper. The current being thus closed, the sulphate of copper is decomposed, sulphuric acid is liberated at the positive pole, while copper is deposited at the negative pole, on the mould suspended from the rod, B, to which, indeed, several moulds may be attached.

The copper plate suspended from the positive pole serves a double purpose; it not only transmits the current, but it keeps the

solution in a uniform state of concentration, for the acid liberated at the positive pole dissolves the copper, and reproduces a quantity of sulphate of copper equal to that which has been decomposed. The bath always remains, therefore, at the same degree of concentration—that is to say, always contains the same amount of salt in

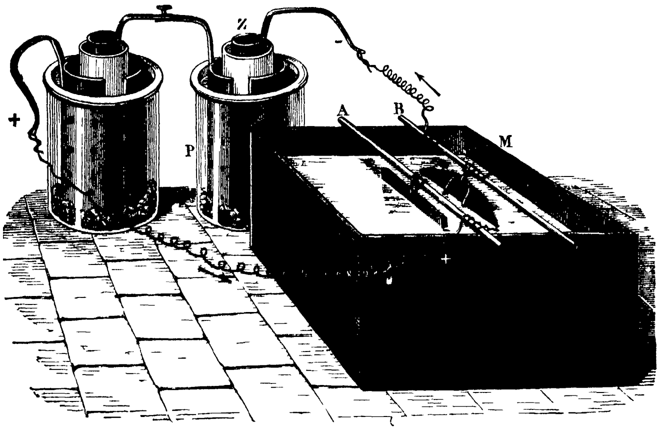


Fig 461

solution, which is a condition necessary for producing a uniform deposit.

481. **Electrogilding.**—The old method of gilding was by means of mercury. It was effected by an amalgam of gold and mercury, which was applied on the metal to be gilded. The objects thus covered were heated in a furnace, the mercury volatilised, and the gold remained in a very thin layer on the objects. The same process was used for silvering; but they were expensive and unhealthy methods, and have now been entirely replaced by electrogilding and electrosilvering. Brugnatelli, a pupil of Volta, appears to have been the first, in 1803, to observe that a body could be gilded by means of the battery and an alkaline solution of gold; but De la Rive was the first who really used the battery in gilding. The methods both of gilding and silvering owe their present high state of perfection principally to the improvements of Elkington, Ruolz, and others.

The difference between electrogilding and electrosilvering and

the processes described in the previous article is this—that, in the former, the metal is deposited on a mould in order to reproduce the objects given ; while, in the latter, the objects themselves are permanently covered with a very thin layer of gold or of silver.

The pieces to be coated have to undergo three preparatory operations.

The first consists in heating them so as to remove the fatty matter which has adhered to them in previous processes.

As the objects to be gilded are usually of copper, and their surface during the operation of heating becomes covered with a layer of suboxide or protoxide of copper, this is removed by the second operation. For this purpose the objects, while still hot, are immersed in very dilute nitric acid, where they remain until the oxide is removed. They are then rubbed with a hard brush, washed in distilled water, and dried in gently heated sawdust.

To remove all spots they must undergo the third process, which consists in rapidly immersing them in ordinary nitric

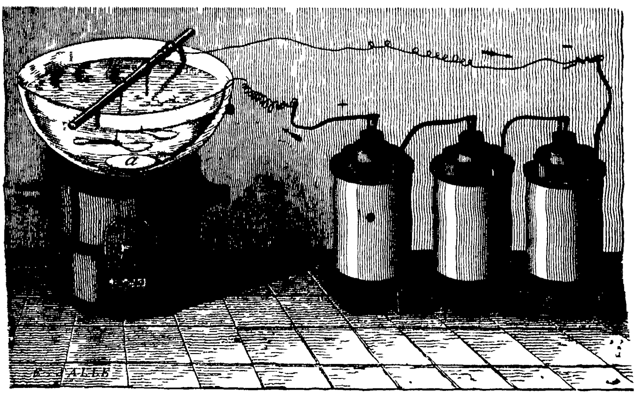


Fig. 462.

acid, and then in a mixture of nitric acid, bay salt, and soot. They are then well washed in distilled water, and dried as before in sawdust.

When thus prepared, the objects are attached to the negative pole of a battery of three or four cells, and if they are to be silvered they must be immersed in a bath of silver kept at a temperature of

sixty to eighty degrees. They remain in the bath for a time which depends on the thickness of the desired deposit. There is great variation in the composition of the bath. That most in use consists of two parts of cyanide of silver and two parts of cyanide of potassium, dissolved in 250 parts of water. In order to keep the bath in a state of concentration, a piece of silver is suspended from the positive electrode, which dissolves in proportion as the silver dissolved in the bath is deposited on the objects attached to the negative pole.

The processes of electrogilding are quite the same as those of electrosilvering, with the exception that a bath of gold is used instead of one of silver, and the positive plate terminates in a plate of gold. The bath used is a solution of cyanide of gold and potassium.

The method which has just been described can not only be used for gilding copper, but also for silver, bronze, brass, German silver, etc. But other metals, such as iron, steel, zinc, tin, and lead, are very difficult to gild well. To obtain a good coating they must first be covered with a layer of copper by means of the battery, and a bath of sulphate of copper ; the copper with which they are coated is then gilded, as in the previous case.

When the layers of metals such as lead deposited by electrolysis are extremely thin, they have colours like those of soap bubbles, and serve thus for metallic coloration. The art of producing such coloured deposits is known as *metallochromy*.

One of the most valuable applications of the electrical deposition of metals, is what is called the *steeling* (*acierage*) of engraved copper plates. The bath required is prepared by suspending a large sheet of iron connected with the positive pole in a vessel filled with a solution of salammoniac, while a thin strip of iron is connected with the negative pole. By this means iron from the large plate is dissolved in the salammoniac, while hydrogen is given off from the small one. When the bath has thus taken up a sufficient quantity of iron, an engraved copper plate is substituted for the small strip. A bright deposit of iron begins to form at once, and the plate assumes the colour of a polished steel plate. The deposit thus obtained in the course of half an hour is exceedingly thin, but it is extraordinarily hard, so that a far larger number of impressions can be taken from a plate thus prepared than from a plate of ordinary copper.

CHAPTER IX.

RELATION BETWEEN ELECTRICITY AND MAGNETISM.

482. **Relation between magnetism and electricity.**—Early in the history of the two sciences, the analogy was remarked which existed between the phenomena of electricity and magnetism. It was observed that in both cases, like kinds of electricity repelled each other, as also did like kinds of magnetism, and that unlike kinds attracted. It had, moreover, been observed that lightning, in striking a ship, often reversed the polarity of compass needles, and even sometimes robbed them of all magnetic power. But though there are many points of resemblance between electricity and magnetism, the dissimilarities are numerous. For instance, magnetic properties cannot be transmitted to good conductors, as can electrical properties. A magnet placed in contact with the earth does not lose its magnetism as does an electrified body. Again, electricity can be produced in all bodies, while magnetism is only manifested by a very small number. Among these resemblances and dissimilarities, nothing could be affirmed respecting the identity of the causes which produce electricity and magnetism until towards the end of 1819, when Oersted, professor of physics in Copenhagen, made a memorable discovery, which for ever intimately connected these two physical agents. Thus arose a new branch of science called *electromagnetism*, to express that the phenomena are at once magnetic and electrical.

483. **Action of currents upon magnets.**—The fact which Oersted discovered was the directive action of currents upon magnets. He found that *electrical currents have a directive action upon the magnetic needle, and always tend to set it at right angles to their own direction.*

To verify this action of currents upon magnets, the experiment is arranged as shown in fig. 463. A magnetic needle, moveable upon a pivot, being at rest in the direction of the magnetic meridian, a wire traversed by a current is brought near it, care being taken to bring it lengthways. The needle is then seen to

deviate from its position of rest, oscillate, and ultimately come to rest in a position which is nearly at right angles to that of the current; and the more nearly so the more powerful is the current.

In this experiment the direction in which the needle is deflected varies with the direction of the current; if it goes from south to north above the needle, the north pole is deflected to the west; if, on the contrary, it goes from north to south but still above the needle, the north pole is deflected to the east. When the current passes below the needle, the same phenomena are reproduced, but in exactly the reverse order. All these different cases were reduced to a single one by Ampère.

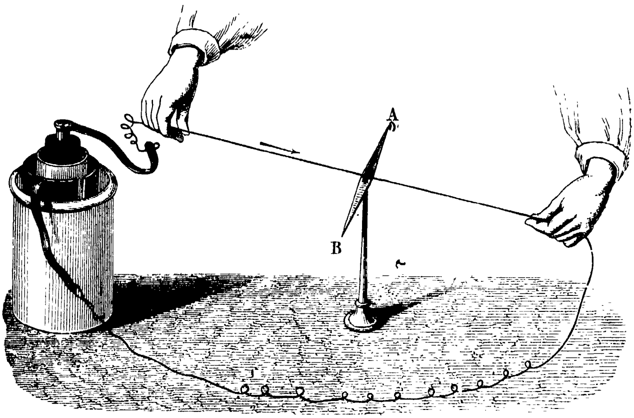


Fig. 463.

484. **Ampère's rule.**—Ampère gave the following *memoria technica*, by which all the various directions of the needle under the influence of a current may be remembered. If we imagine an observer placed in the connecting wire in such a manner that the current entering by his feet issues by his head, and that his face is always turned towards the needle, we shall see that in the above four positions the north pole is always deflected towards the left of the observer. By thus personifying the current, the different cases may be comprised within this general principle; *In the directive action of currents on magnets, the north pole is always deflected towards the left of the current.*

485. **Action of magnets and of the earth on currents.**—Just as voltaic currents act on magnets, so also magnets act upon currents. To prove this, a circle of copper wire, provided at the end with steel points, dips in two mercury cups (fig. 464). These mercury cups are at the ends of two metal rods attached to two vertical columns, with which can be connected the poles of Bunsen's element. By this arrangement, which is known as *Ampère's stand*, we have a movable circuit continually traversed by a current. When this circuit is at rest, if a powerful magnet be placed beneath the circuit but in its plane, the circuit will be seen to turn and *set transversely to the length of the bar, which is the converse of Oersted's experiment.*

The terrestrial globe, which acts like a magnet on magnetic

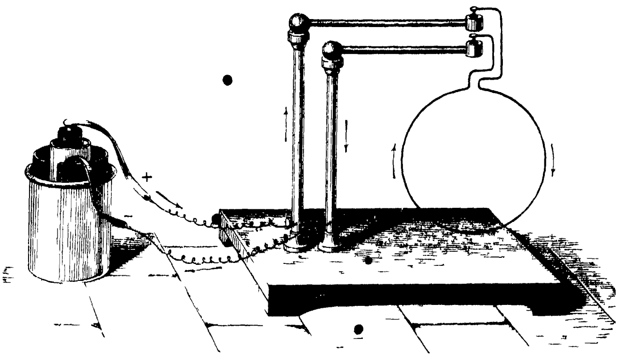


Fig 464

needles, acts in the same manner on the movable circuits, that is, it causes them to set at right angles to the magnetic meridian. This action may be demonstrated by the above apparatus. With this object, before the current traverses the circuit, the ring is placed in the magnetic meridian, and then the two poles of the battery are connected with the two columns; the circuit is soon observed to set transversely to its first position, and in such a way that, in the lower part of the circuit, the direction of the current is from east to west.

486. **Galvanometer, or multiplier.**—The name *galvanometer*, *multiplier*, or *rheometer* is given to a very delicate apparatus, by which the existence, direction, and intensity of currents may be

determined. It was invented by Schweigger, in Germany, a short time after Oersted's discovery.

In order to understand its principle, let us suppose a magnetic needle, *ab*, suspended by a silk thread (fig. 465), and surrounded, in the plane of the magnetic meridian, by a copper wire forming a complete circuit round the needle in the direction of its length. When this wire is traversed by a current, it follows, from what has been said in the previous article, that in every part of the circuit an observer lying in the wire in the direction of the arrows, and looking at the needle, *ab*, would have his left always turned towards the same point of the horizon, and consequently that the action of the current in every part would tend to turn the north pole in the same direction; that is to say, that the actions of the four branches of the circuit concur to give the north pole the same direction. By coiling the copper wire in the direction of the needle, as represented

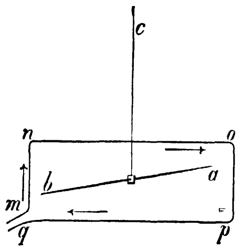


Fig. 465.

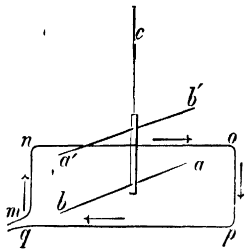


Fig. 466.

in the figure, the action of the current has been *multiplied.* If, instead of a single one, there are several circuits, provided they are insulated, the action becomes still more multiplied, and the deflection of the needle increases; or, what is the same thing, a much feebler current will produce a given deflection.

As the directive action of the earth continually tends to keep the needle in the magnetic meridian, and thus opposes the action of the current, the effect of the latter is increased by using an astatic system of two needles as shown in fig. 466. The action of the earth on the needle is then very feeble, and, further, the actions of the current on the two needles become accumulated. In fact, the action of the circuit, from the direction of the current indicated by the arrows, tends to deflect the north pole of the lower needle *ab*

towards the west. The upper needle, *a′ b′*, is subjected to the action of two contrary currents, *no* and *qp*, but as the first, *no*, is nearer, its action preponderates. Now this current *no*, passing below the needle, evidently tends to turn the pole, *a′*, towards the east, and consequently the pole, *b′*, towards the west; that is to say, in the same direction as the pole, *a*, of the other needle.

From these principles it will be easy to understand the explanation of the *multiplier*. The apparatus represented in fig. 467 consists of a thick brass plate resting on levelling screws; on this is a copper frame on which is coiled a great number of turns of wire covered with silk. The two ends terminate in binding screws,

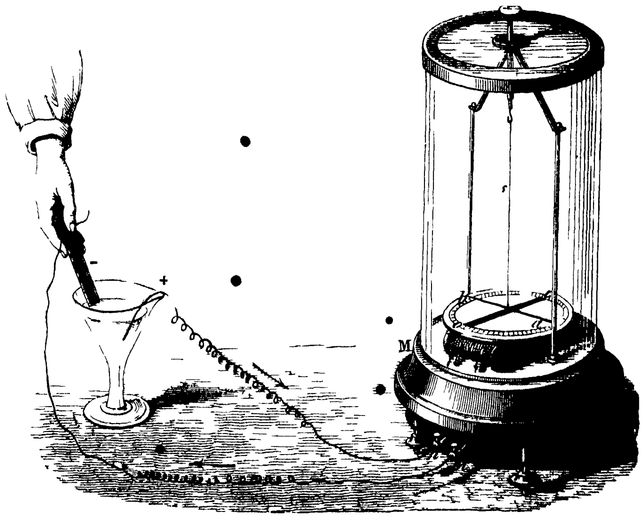


Fig 467

n and *m*. Above the frame is a graduated circle, with a central slit parallel to the direction in which the wire is coiled. By means of a very fine filament of silk, an astatic system is suspended; it consists of two needles, *ab* and *a′ b′*, one above the scale, and the other within the circuit itself.

In using the instrument it is so adjusted that the needles, and also the slit, are in the magnetic meridian.

487. **Uses of the galvanometer.**—To show, by means of the multiplier, the electricity developed in chemical actions, for instance in the action of acids on metals, two platinum wires may be attached to the binding screws, *m* and *n*. One of them is then plunged in very dilute sulphuric acid, and the other placed in contact with a piece of zinc held in the hand, which is dipped in the liquid. An immediate deflection is observed, which indicates the existence of a current; and from the direction which the north pole of each needle assumes, it is seen that the direction of the current is that indicated by the arrows. From which we may conclude, in accordance with the explanation given as to the origin of electricity in the simple voltaic circuit, that the acid is positively electrified and the zinc negatively.

The length and diameter of the wire vary with the purpose for which the galvanometer is intended. For one which is to be used in observing the currents due to chemical actions, a wire about $\frac{1}{8}$ millimetre in diameter, and making about 800 turns, is well adapted. Those for thermo-electric currents, which have low intensity, require a thicker and shorter wire, for example, thirty turns of a wire $\frac{3}{8}$ millimetre in diameter. For very delicate experiments, as in physiological investigations, galvanometers with as many as 30,000 turns have been used.

488. **Tangent galvanometer.**—This is a form of galvanometer specially suited for measuring the strength of currents. It consists of a small number of turns of stout wire, or even of a single one, forming a ring of 8 or 10 inches in diameter (G, fig. 468). In the centre is suspended a small magnetic needle not more than about an inch in length and playing over a graduated scale, by which the deflection can be measured; as this is difficult with so small a needle, it is provided with a long light index.

If now the ring be placed in the magnetic meridian, and different elements or different batteries are connected with the binding screws, it will be found that the magnetic needle is deflected to varying extents; and it can be shown with strict accuracy that the strengths of the various currents are proportional, not to the angles of deflection themselves, but to the trigonometrical *tangents* of such angles; and it is from this property that the name of the apparatus is derived.

We have already seen that in a complete voltaic circuit there is always a certain force at work to which is due the production of electrical effects in the circuit, and to which the term *electromotive*

force (467) is applied. Now any circuit is made up of various materials : the metals themselves, the exciting liquid, the wires ; the apparatus used to detect or measure the strength of the current, or to demonstrate its effects. No substance whatever is a perfect conductor ; all offer a certain obstacle or *resistance* to the passage of the electricity (417), and this resistance varies greatly according to the dimensions of the materials, and their special nature. The strength of current produced by any given combination depends on the ratio of these two factors ; it is directly proportional to the electromotive force, and is inversely proportional to the resistance, so that with a given electromotive force the current is stronger the smaller the resistance, and, conversely, with a fixed resistance the current is stronger the greater the electromotive force. This is the princple known as *Ohm's law.*

In voltaic combinations a distinction is drawn between the *internal* and the *external* resistance ; the former being that which is offered by the liquid between the plates, while the external resistance includes the joining wires, and the whole of the apparatus in which the electrical effects are to be produced.

We shall make use of the tangent galvanometer to demonstrate the laws of electrical resistance, a point of great importance both from the practical and theoretical point of view.

488*a*. **Laws of electrical resistance.**—Suppose we connect a constant element, B (471), with the binding screws of a tangent

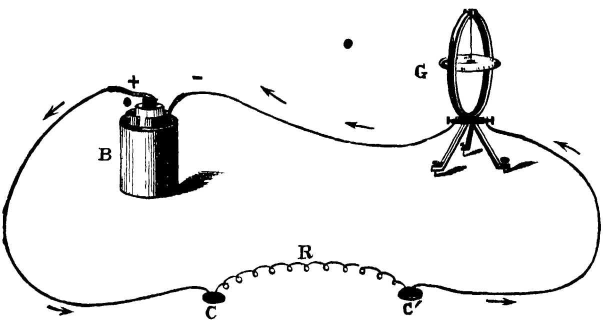


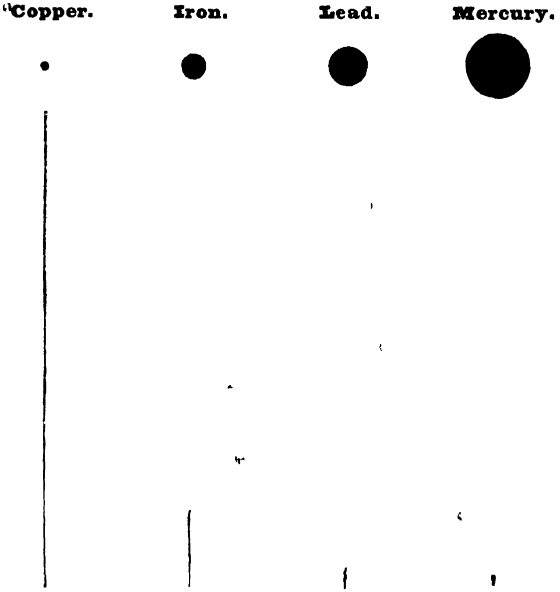
Fig 468

galvanometer, G, in the manner represented in fig. 468, in which C and C′ are two mercury cups, which enable us readily to introduce into the circuit wires of different materials and dimensions. If in

the first case the coiled wire, R, represents a short length of the same wire as the connecting wires, which are usually copper, the needle of the galvanometer will be deflected through a certain angle, and the tangent of this angle is a measure of the strength of the current.

Suppose now a greater length of the same wire be interposed,

RELATIVE CROSS SECTIONS OF WIRES WHICH FOR THE SAME LENGTH OFFER EQUAL RESISTANCES.



RELATIVE LENGTHS OF WIRES WHICH FOR THE SAME CROSS SECTION OFFER EQUAL RESISTANCES.

Fig. 469.

the angle of deflection will be smaller, showing that the current is weaker, and by the introduction of a still greater length it will be still more enfeebled. Hence, other things being equal, the current is weaker when it has to traverse a greater length of a given conductor, or the *resistance of a body increases with its length.*

If now we substitute for the original wire R, another wire of the

same length and the same material, but of smaller diameter, the current is weaker, and by taking a still thinner wire it is again more enfeebled ; on the contrary, if the same length of wire, of the same material but of greater diameter, be introduced, the current is stronger. Hence *the smaller the section of a conductor the greater is the resistance.*

Again, if for the original copper wire we take a wire of the same length and the same diameter, but of some different material, such as iron, we shall find that the current is weaker ; and if the wire be of platinum or of lead it is still more enfeebled, showing that *the resist ınce of a body depends on its specific nature.*

Continuing and varying these experiments, we arrive at the following general laws : *the resistance of any body is directly pri-portional to its length, and is inversely proportional to its cross section and its conductive power.*

Of all substances in ordinary use copper is by far the best conductor, especially when pure ; for then it is exceeded by perhaps only one metal—silver. Fig. 469 represents the relations of a few of the metals in this respect.

The quality of a metal has a great influence on its conducting power ; the presence in copper of minute traces of certain substances, which it would be difficult to determine by chemical methods, greatly diminishes its conductivity or, what is the same thing, increases its resistance. This is very important in the wires used in long lines of telegraph communication, more especially in the submarine cables (502). An impurity in the wire, which has the effect of reducing its conductivity, would have the same effect as if the current had to traverse an additional number of miles of the wire.

The resistance of liquids is much greater than that of metals ; thus dilute sulphuric acid, which has the highest conductivity of all liquids, has about 20,000,000 times as great a resistance as copper.

Those metals which have a high conducting power for heat are those also which are good conductors of electricity.

The resistance of a body varies with the temperature; that of metals is increased by increase of temperature, while that of liquids is diminished. Hence it is that the current of batteries is greater after they have been closed for a while, for whenever the current is closed, heat is produced in all parts of it, including the liquids.

488*b*. **Electrical units.**—It is perhaps the most characteristic feature of the modern progress of electricity that, not only for purely scientific purposes, but also for the most ordinary practical appli-

cations, the quantities of electricity concerned can be determined with as great accuracy as can any weighing and measuring in daily life. All electrical measurements may be expressed by reference to certain fundamental standards, just as in ordinary life we have certain standards of weight and length. In an elementary work it is not practicable to give any adequate, and yet brief, account of the scientific basis of this system of electrical measurements, and we may content ourselves with adopting and using them, just as we use the pound as standard of weight and the foot as measure of length without concerning ourselves with the reasons for the adoption of these standards.

The principal standard electrical units are those of resistance, the *ohm* ; of electromotive force, the *volt* ; and of strength of current, the *ampère*. The *ohm* is equal to the resistance offered by a column of mercury a square millimetre in cross section and 1·06 metre in length. For convenience it is usually represented by a certain length of wire of a definite material and diameter. Such a length of wire is called a *resistance coil*, and is usually employed in a *resistance box*. Fig 470 represents the way in which several such coils are arranged in the inside of a box. Each coil consists of a certain length of insulated wire representing a definite resistance and wound double; the ends are connected to solid pieces of brass. These pieces are not in contact, but can be made so by putting in a plug of the same metal.

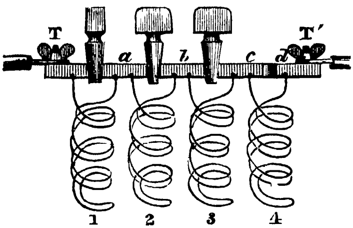


Fig. 470.

If the terminals of a circuit are connected with T T′, fig 470, and all the plugs are inserted, the resistance box offers no appreciable resistance, for the current passes by the plugs and the massive metal ; but by taking out any of the plugs the current has to pass through the wire coil between the two brass pieces, and thus its resistance is introduced into the circuit. In the figure this represents the use of a resistance of 4 ohms.

The coils are in multiples and submultiples of ohms, and are so arranged that their combination may be as greatly varied with as few resistances as possible. Thus a set of eleven coils of 0·1, 02 0·2, 0·5, 2, 2, 5, 10,10, 20, and 50 enables us to introduce any resistance from 0·1 to 100 into the circuit.

We may form an idea of the resistance of an ohm by saying that 125 yards of No. 16 copper wire has a resistance of one ohm.

A resistance of one thousand ohms is called a *megohm*, and a resistance of $\frac{1}{1000}$ of an ohm is a *microhm*.

A mile of No. 8 iron telegraph wire has a resistance of about 14 ohms to the mile.

The *volt*, or unit of electromotive force, is not represented by any special standard. The electromotive force of a Daniell's element is about 1·08 volt; that of a Leclanché is 1·46, and that of a Bunsen 1·8 volt.

The *ampère*, or unit of strength of current, is defined from Ohm's law (488) as being that current which would be produced by an electromotive force of a volt acting through a resistance of an ohm. A *milliampère* is the $\frac{1}{1000}$ of an ampère. The currents in ordinary use for electric lighting have a strength of from 10 to 70 ampères or even more; those in working the telegraph from 14 to 16 milliampères. An ordinary-sized Daniell's element with an internal resistance of 1·3 will give a current of 0·8 ampère when put on *short circuit*, or *short circuited* as it is technically called; that is to say, when closed by a wire which has no appreciable resistance. In like manner a Bunsen's element whose internal resistance may be taken at $\frac{1}{10}$ of an ohm, will produce a current of 18 ampères.

CHAPTER X.

ELECTRODYNAMICS.

489. **Reciprocal action of currents on currents.**—Ampère did not restrict himself to trying the action of magnets and of the earth upon movable currents; he went further, and was led to the important discovery that electrical currents act on each other as do magnets; and out of this has arisen an entirely new branch of physics, to which the name *electrodynamics* has been given. The actions which currents exert on each other are different according as they are parallel or angular.

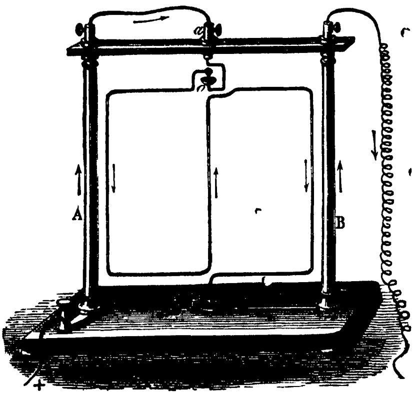


Fig 471.

I. *Two currents which are parallel, but in contrary directions, repel each other.*

II. *Two currents, parallel and in the same direction, attract each other.*

To verify these laws use may be made of the apparatus represented in fig. 471. On a wooden base are fixed two brass columns, A and B, joined at the top by a wooden cross-piece. In the centre of this is a brass binding screw, *a*, and below this a mercury cup, *o*. In this is placed an iron pivot which joins the end of a copper wire. This wire is coiled in the manner represented in the figure, terminating in a mercury cup, C, on the base of the apparatus. It thus forms a circuit movable about the pivot.

This being premised, the circuit is arranged in the plane of the two columns, as shown in fig. 471, and the current from a Bunsen's battery is passed through it to the foot of the column A; it passes

thence by a copper wire to the binding screw, *a*; thence into the cup, *o*, traverses the entire movable circuit in the direction of the arrows, reaches the cup, C, whence by a copper strip it passes to the foot of the column, B, rises in this, and ultimately returns to the battery. When the current passes, the circuit moves away from the columns, and, after a few oscillations, comes to rest crosswise to its original position; thus showing that the ascending current in the columns and the descending current in the circuit repel each other, thereby proving the first law.

The second law may be established by means of the same apparatus, replacing the movable circuit depicted in fig. 471, by another so arranged that the current ascends in both the columns and in the two branches of the circuit. When the movable circuit is displaced, and the current is passed, the latter returns briskly towards the columns.

Law of angular currents. In the case of two angular currents, one fixed and the other movable, Ampère found that there was attraction when both the currents moved towards, or both away from, the apex of the angle; and that repulsion took place when, one current moving towards the apex, the other moved away from it.

490. **Roget's Vibrating Spiral.**—The attraction between currents in the same direction may be very beautifully illustrated by *Roget's vibrating spiral* (fig. 472). A spiral of copper wire is fixed at one end to a binding screw, attached to an adjustable metal support, *a*; which together with a binding screw, terminating in a cup, are fixed on a nonconducting base. At the lower end of the spiral is a small weight, and it dips in mercury in the cup. The poles of a battery being connected with the binding screws, the spiral at once begins to oscillate up and down. For the individual turns of the spiral are traversed by the current and attract each other; the spiral becomes shorter, its lower end no longer dips in the mercury, and the current ceases to pass. Owing to their weight, the windings, being no longer attracted, sink again, the end dips in mercury, the current again passes, the individual turns again attract each other, and so on.

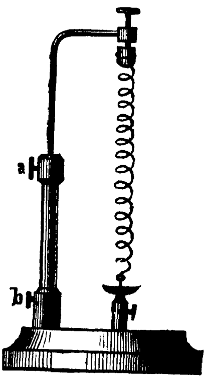


Fig. 472.

SOLENOIDS.

491. **Structure of a solenoid.**—A solenoid is a system of equal and parallel circular currents formed of the same piece of covered copper wire, and coiled in the form of a helix or spiral, as represented in fig. 473. A solenoid, however, is only complete when part of the wire, BC, passes in the direction of the axis in the interior of the helix. With this arrangement, when the circuit is suspended in the mercury cups, *ab*, of the apparatus (fig. 472), and a current is passed through, it is directed by the earth exactly as if it were a magnetic needle. If the solenoid be removed it will, after a few oscillations, return so that its axis is in the magnetic meridian. Further, it will be found that, in the lower half of the coils of which the

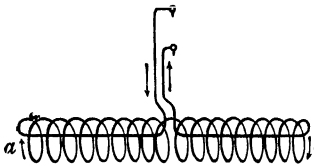


Fig. 473.

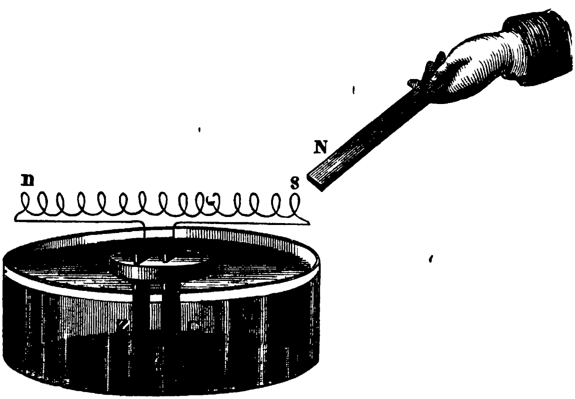


Fig. 474.

solenoid consists, the direction of the current is from east to west; in other words, the current is *descending* on that side of the coil turned towards the east, and ascending on the west. In this experiment the solenoid is directed like a magnetic needle, and the *north pole*, as in magnets, is that end which points towards the north, and the *south pole* that which points towards the south.

492. **De la Rive's floater.**—The properties of solenoids may be very conveniently illustrated and studied by means of what is known as *De la Rive's floater.* This consists of a copper wire bent in a ring or twisted in the form of a solenoid, the ends of the wire being passed through a cork and soldered respectively to small plates of zinc and copper (fig. 474). If this apparatus be floated on a basin of slightly acidulated water, the voltaic action set up between the plates produces a current which traverses the solenoid. This then sets in a direction of magnetic north and south, and behaves in this respect just as if it were a magnet floated on the piece of cork.

If, instead of the solenoid in fig. 475, the wire be coiled in the form of a ring, and the pole of a magnetised bar be presented to the

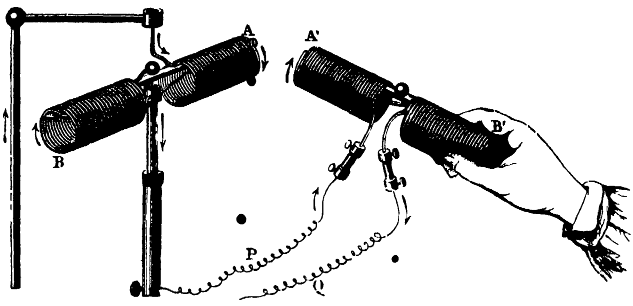


Fig. 475.

ring, it will be seen to move along the rod, which it encircles towards the middle, where it remains stationary. This action is explained by considering the way in the Ampèrean currents circulate in the wire and the magnetised rod. If the pole presented is such that they are in opposite directions, the coil will be repelled, turn round and move along the bar as before.

493. **Mutual actions of magnets and solenoids.**—Exactly the same phenomena of attraction and repulsion exist between solenoids and magnets as between magnets. For if one of the poles of a magnet be presented to a movable solenoid, traversed by a current, attraction or repulsion will take place, according as the poles of the magnet and of the solenoid are of contrary or of the same name (fig. 475). The same phenomenon takes place when a solenoid, traversed by a current and held in the hand, is presented to a movable mag-

netic needle. Hence the law of attractions and repulsions applies to the case of the mutual action of solenoids and of magnets.

494. **Mutual actions of solenoids.**—When two solenoids traversed by a powerful current are allowed to act on each other, one of them being held in the hand, and the other being movable about a vertical axis, as shown in fig. 475, attraction and repulsion will take place just as in the case of two magnets. These phenomena are readily explained by reference to what has been said about the mutual actions of the currents, bearing in mind the direction of the currents in the ends A and A′ presented to each other.

495. **Ampère's theory of magnetism.**—Ampère propounded a most ingenious theory, based on the analogy which exists between solenoids and magnets, by which all magnetic phenomena may be referred to electrodynamical principles.

Instead of attributing magnetic phenomena to the existence of two fluids, Ampère assumed that each individual molecule of a magnetic substance is traversed by a closed electric current. When the magnetic substance is not magnetised, these molecular currents, under the influence of their mutual attractions, occupy such positions that their total action on any external substance is null. Magnetisation consists in giving to these molecular currents a parallel direction, and the stronger the magnetising force, the more perfect the parallelism. The *limit of magnetisation* is attained when the currents are completely parallel.

The resultant of the actions of all the molecular currents is equivalent to that of a single current which traverses the outside of a magnet. For by inspection of fig. 476, in which the molecular currents are represented by a series of small internal circles in the two ends of a cylindrical bar, it will be seen that the adjacent parts of the currents oppose one another, and cannot exercise any external electrodynamic action, which is not the case with those on the surface.

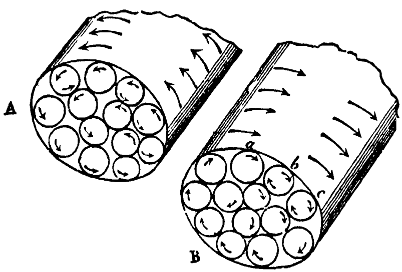


Fig. 476.

The direction of these currents in magnets can be ascertained by considering the suspended solenoid (fig. 473). If we suppose

it traversed by a current, and in equilibrium in the magnetic meridian, it will set in such a position that in the lower half of each coil the current flows from *east to west.* We may then establish the following rule.

At the north pole (English) of a magnet the direction of the Ampèrean currents is opposite that of the motion of the hands of a watch, and at the south pole the direction is the same as that of the hands.

496. **Terrestrial current.**—In order to explain terrestrial magnetic effects on this supposition, the existence of electrical currents is assumed which continually circulate round our globe from east to west, perpendicular to the magnetic meridian.

The resultant of their action is a single current traversing the magnetic equator from east to west. These currents are supposed to be thermoelectric currents (517) due to the variations of temperature caused by the successive influence of the sun on the different parts of the globe from east to west.

These currents direct magnetic needles; for a suspended magnetic needle comes to rest when the molecular currents on its under surface are parallel, and in the same direction as the earth currents. As the molecular currents are at right angles to the direction of its length, the needle places its greatest length at right angles to east and west, that is it sets north and south. Natural magnetisation is probably imparted in the same way to iron minerals.

496*a*. **Vibrating wire. Barlow's wheel.**—An interesting example of the action of a magnet on an electrical current is seen in the experiment represented in fig. 477. HQ is a wire playing in a loop connected with one pole of a battery, the other pole of which leads to a groove containing mercury which is between the poles of a horse-shoe magnet. When the current passes, the wire vibrates either towards the magnet or away from it according to the direction in which the current passes. This is readily understood if we consider the direction of the imaginary currents circulating in the magnets on Ampère's hypothesis. The molecular currents *ab* and *cd* on the side next the wire determine the motion; they attract a current going in the same direction HQ, and the wire is moved inwards. Its contact with the mercury is soon broken, the current

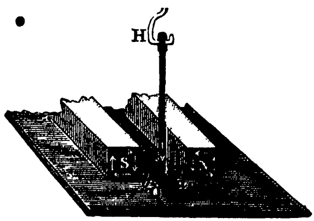


Fig. 477.

then ceases to pass, it falls again by its own weight, the current is again made, and so on, the end of the wire vibrating continually in and out of the mercury. If the current is in the opposite direction, that is from Q to H, there is repulsion between the molecular currents in the magnet and in the wire, the molecular currents repel this, and the vibration is towards the outside.

A further interesting illustration is afforded by *Barlow's wheel* (fig. 478). This consists of a light copper disc, with deep indentations, forming a sort of star rotating easily in a fork, and the points just dipping in a groove containing mercury between the poles of a horse-shoe magnet. When wires from a battery are connected as shown in the figure, the star at once rotates, and the direction of the rotation depends on the direction of the current. Instead of the vibrating wire in the former experiment, the current enters the wire by one of the spokes; it is projected outwards, contact is made by another spoke, and these follow in such rapid succession as to produce a continuous rotation.

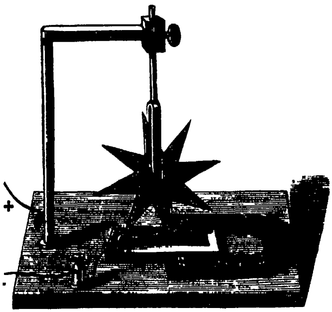


Fig. 478.

Barlow's wheel is interesting as illustrating the action of Gramme's and some other forms of magnetoelectrical machine (511*a*). If the experiment be reversed, if, for instance, the wires in the figure are connected with any arrangement for showing the passage of electricity, such as a galvanometer, instead of being connected with the battery, and if then the star be rotated rapidly by mechanical means, a current of electricity will be produced, as will be shown by the deflection of the needle.

CHAPTER XI.

ELECTROMAGNETS. TELEGRAPHS AND ELECTROMAGNETIC MOTORS.

497. **Magnetisation by electrical currents. Electromagnets.**—From the influence which currents exert upon magnets, turning the north pole to the left and the south pole to the right, it is natural to think that by acting upon magnetic substances in the natural state the currents would tend to separate the two magnet-

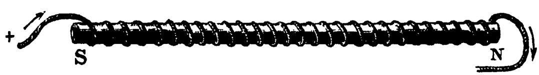


Fig. 479.

isms. In fact, when a wire traversed by a current is immersed in iron filings, they adhere to it in large quantities, but become detached as soon as the current ceases, while there is no action on the filings of any nonmagnetic metal.

The action of electrical currents on magnetic substances is well seen in an experiment due to Ampère, which consists in coiling an insulated copper wire round an unmagnetised steel bar (fig. 479).

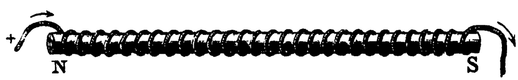


Fig. 480.

If a current be passed through the wire, even for a short time, the bar becomes strongly magnetised; the action is promoted by moving the steel backwards and forwards while the current is passing; the same effect is produced with a bar of soft iron, but in this case the magnetisation is temporary; when the current ceases, the iron, which when properly prepared is almost entirely destitute of coercive force, reverts instantaneously to the natural state. If the end

of the spiral in fig. 480 be looked at, it will be seen that the winding is in the same direction as the hands of a watch, and in that case the end at which positive electricity enters is the south pole; if the wire is coiled round the bar in the opposite direction (fig. 480), the end at which positive electricity enters is the north pole. Both these cases come under the general principle that if we imagine an observer floating in the direction of the current, and looking at the iron core, the north pole is always on his left hand.

We have seen (fig. 430) that if the charge of a Leyden jar be transmitted through a spiral, a rod placed in it is also magnetised. This experiment succeeds very well with a knitting needle; and, if we consider the direction in which the positive electricity passes, it will be found that the polarity of the needle when magnetised is in accordance with the above rule.

Electromagnets are bars of soft iron which, under the influence of a voltaic current, become magnets; but this magnetism is only temporary, for the coercive force of perfectly soft iron is null, and the magnetism ceases as soon as the current ceases to pass through the wire. If, however, the iron is not quite soft, it retains more or less traces of magnetisation. Electromagnets have the horse-shoe form, as shown in fig. 481, and a copper wire, covered with silk or cotton, is rolled several times round them on the two branches, so as to form two bobbins, A and B. In order that the two ends of the horse-shoe may be of opposite polarity, the winding on the two limbs, A and B, must be such that if the horse-shoe were straightened out it would be in the same direction.

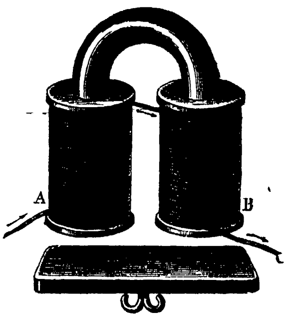


Fig. 481.

Electromagnets, instead of being made in one piece, are more usually constructed of two iron cylinders, firmly screwed to a stout piece of the same metal. Such are the electromagnets in Morse's telegraph (502), the electromagnetic engine (508). The helices on them must be such that the current shall flow in the same direction as the hands of a watch as seen from the south pole, and against the hands of a watch as seen from the north pole.

The force of such magnets depends on their dimensions, on the number of turns of wire, and on the strength of the current. An

electromagnet need not be very powerful to support one person (fig. 482).

498. **Electric telegraphs.**—These are apparatus by which signals can be transmitted to considerable distances, and with enormous speed, by means of voltaic currents propagated in metal wires. Towards the end of the last century, and at the beginning of the present, many philosophers proposed to corre-

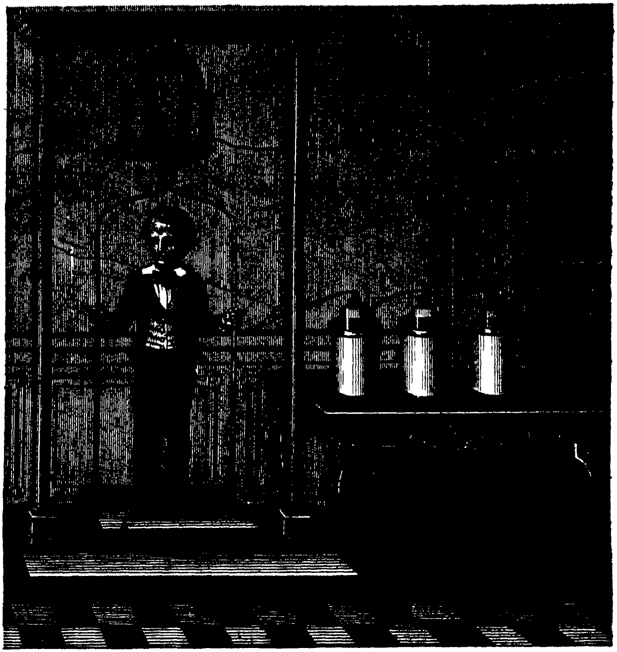


Fig. 482.

spond at a distance by means of the effects produced by electrical machines when propagated in insulated conducting wires. In 1811, Sœmmering invented a telegraph in which he used the decomposition of water for giving signals. In 1820, at a time when the electromagnet was unknown, Ampère proposed to correspond by means of magnetic needles, above which a current was sent, as

many wires and needles being used as letters were required. In 1834, Gauss and Weber constructed an electromagnetic telegraph, in which a voltaic current transmitted by a wire acted on a magnetised bar; the oscillations of which under its influence were observed by a telescope. They succeeded thus in sending signals from the Observatory to the Physical Cabinet in Göttingen, a distance of a mile and a quarter, and to them belongs the honour of having first demonstrated experimentally the possibility of electrical communication at a considerable distance. In 1837, Steinheil in Munich, and Wheatstone in London, constructed telegraphs in which several wires each acted on a single needle: the current in the first case being produced by an electromagnetic machine, and in the second by a constant battery.

Every electric telegraph consists essentially of three parts: 1, a

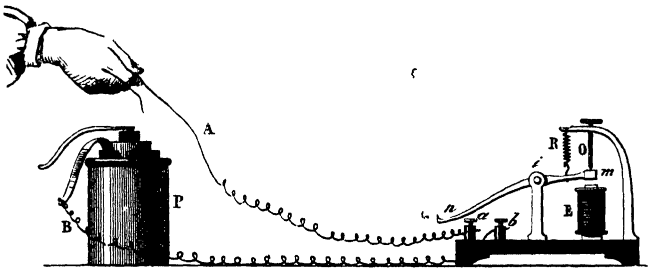


Fig. 483.

circuit, consisting of a metallic connection between two places, and an *electromotor*, for producing the current; 2, a *communicator* or *sender*, for sending the signals from one of the stations; and, 3, an *indicator* or *receiver*, for receiving them at the other station. The manner in which these objects, especially the last two, are effected can be greatly varied. The three principal systems are the needle telegraph, the dial telegraph, and the printing telegraph.

The *needle telegraph* is essentially a vertical galvanometer (486); that is to say, a magnetic needle suspended vertically in a coil of insulated wire. To the needle is attached an index, which is seen on the front of the apparatus. The signs are made by transmitting the current in different directions through the multiplier, by which the needle is deflected either to the right or left, according to the will of the operator. The instrument by which this is effected is called a key, or *commutator*.

In the *dial* telegraph an electromagnet causes an index to move over a dial provided with the twenty-six letters of the alphabet, that letter in front of which the needle stops being the letter sent. By this kind of telegraph messages are not sent with great rapidity, and the mechanism is somewhat complicated and apt to get out of order; yet, as the manipulation is very simple, it is occasionally used in private offices.

499. **Principle of Morse's telegraph.**—This telegraph is based *on the temporary magnetisation of soft iron by the intermittent passage of currents.* Thus let E (fig. 484) be a fixed electromagnet, the insulated wires of which are attached to the two binding screws, *a* and *b*. Above this electromagnet is a lever, *mn*, movable about an axis, *i*, and ending in an armature of soft iron, *m*, so that, whenever the electromagnet is traversed by a current, the armature

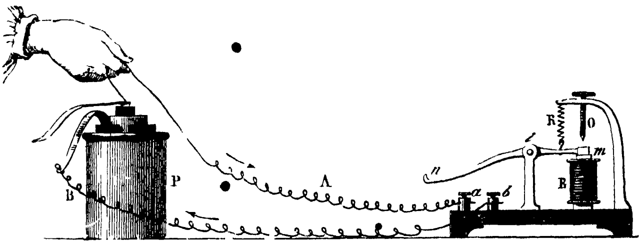


Fig 484.

is attracted, and the part of the lever on the right of the fulcrum is lowered; then, when the current no longer passes, a spring, R, raises the lever to an extent regulated by a screw, O.

Suppose, for example, the electromagnet is at Bristol, and that there is a cell, P, at London, and two metal wires, A and B, by one of which the binding screw, *b*, is permanently connected with the negative pole of the battery, while the experimenter holds the other wire in his hand. So long as the experimenter does not place the wire, which he holds in his hand, in contact with the positive pole, the current does not pass; and as the electromagnet does not act, the arm, *im*, of the lever is raised (fig. 483). But the moment contact is made, the current is closed, the electromagnet attracts, and the arm, *im*, is lowered (fig. 484); but it resumes its original position as soon as contact is broken, and so on at the will of the operator. Thus one person at London can cause the lever, *mn*, to

oscillate at Bristol as often and as rapidly as possible as he desires. This is, in its simplest form, the principle of the elementary mechanism of electric telegraphs based on electromagnetism. It only remains to give to these oscillations a definite meaning (503).

500. **Line wire.**—Of the various essentials for a telegraphic communication, the batteries or sources of power have been already described, and we shall therefore pass to the explanation of the *circuit*, or *line wire*.

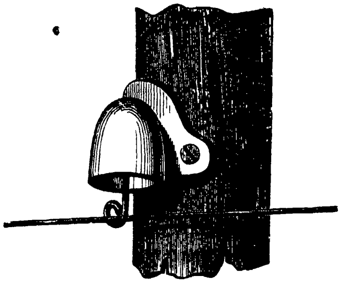


Fig. 485.

Line wires are either *air*, *subterranean*, or *submarine*.

The air wire consists of a stout galvanised iron wire connecting two stations. At certain intervals are wooden posts, to which are attached insulating supports of porcelain, which sustain the wire (fig. 485). Subterranean wires are used for cases in which an aërial wire would not be sufficiently protected against accident, as in towns. They usually consist of copper wires covered with gutta-percha ; this insulates them from the earth in which they are placed.

Submarine wires or cables are such as are employed in deep seas, where great strength is required. The ordinary form is

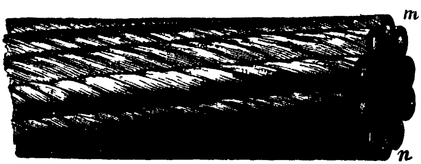


Fig. 486.

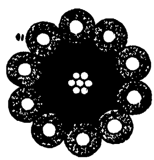


Fig. 487.

represented in figs. 486 and 487. The *core* consists of seven fine wires of very pure copper, which are twisted together and surrounded by an insulating coating. This is surrounded by an insulating coating of four consecutive layers of gutta-percha alternating with the same number of layers of a material known as *Chatterton's compound*, which is essentially a mixture of resin, pitch, and gutta-

percha applied hot. Round this is a layer of tarred hemp, and this again is surrounded by a protective coating of steel wire coated with tarred hemp, which preserves it from the corrosive action of the sea.

Fig. 486 gives a longitudinal view of a submarine cable, and fig. 487 a cross section. The diameter of such a cable is about an inch, it weighs about a ton to the mile and its resistance is from $3\frac{1}{2}$ to 10 ohms.

501. **The earth as a conductor.**—In figs. 483 and 484 we have not merely a wire connecting the positive pole of the battery with the electromagnet, but there is a second one which acts as a return wire. In 1873 Steinheil made the very important discovery that the earth might be utilised for the return conductor. This has

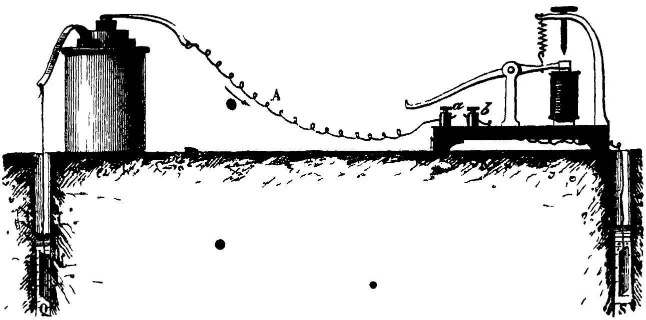


Fig. 488.

the twofold advantage of doing away with the expense of a second wire and also of lessening the resistance.

With this view, at the sending station, a copper wire is attached to the negative pole, which is fixed at the other end to a copper plate, Q. This plate is placed in water if possible (fig. 488), or at all events is sunk some depth in earth, the object being the same as in making the earth connection of a lightning conductor. In like manner, at the receiving station, a similar wire and plate, S, are connected with the binding screw, *b*. Thus, while the negative electricity passes into the ground by the plate, Q, the positive electricity which reaches the electromagnet and the binding screw enters the ground by the plate S. Hence there is in the wire, A, and in the electromagnet the same circulation of electricity, and therefore the same effects as when the binding screw, *b*, communi-

cates directly with the negative pole of the battery by means of a metal wire.

502. **Morse's telegraph.**—Fig 489 represents a station at which a despatch is being sent by the help of this apparatus, and fig 490 represents the receiving station At each station the apparatus is the same, it is double, and consists of two distinct parts—the *key*, by which the signals are sent, and the *receiving*

Fig 489

instrument, which registers them The two parts are represented on a larger scale in figs 491 and 492

To understand how they work let us begin with fig 489 Below the table is a box containing the battery, which furnishes the current. This passes by the wire, B, into the key, which will be afterwards described (fig 491). Thence it passes into a small

galvanometer, g, which indicates by the deflection of its needle whether the current is passing or not. The current ultimately attains the piece, M, which acts as a lightning conductor, as we shall afterwards see, and thence it goes to the wire, L, which is the *line wire.*

This wire is again seen at the top of fig. 490, whence the

Fig. 490.

arriving current again passes into the lightning conductor, then into a galvanometer, and next to a key, whence it passes into the electromagnet, which makes part of the receiver. It then enters the wire, T, which leads it to earth.

503. **Morse's key and receiving instrument.**—The general arrangement of the apparatus being understood, the following are

the details of its action. The *key* consists of a small mahogany base, which acts as a support for a metallic lever, *hk* (fig. 491), movable in its middle on a horizontal axis. The end, B, of this lever is always pressed upwards by a spring, *r*, beneath; at the other end a screw passes through it, which rests on a small metal support, in contact with the wire, A. Fig. 491 represents the key at the moment it receives the despatch, as at work for instance in fig. 492. The current enters then by the wire, L, which is the line wire, rises into the lever, *hk*, and descends by the screw pin, *a*, into the wire, A, which leads to the indicator. If, on the other hand, the key is to be used for sending a message, as represented in fig. 489, it will be seen that the lever, *kh*, does not touch the metal pin in which the wire, P, terminates. But if the lever, *h*, is lowered by pressing the end, B, contact is set up, and the current, P, at once passes into the lever, *hk*, and thence into the wire, L, which leads it to the station signalled to; for the same wire is used to send and to receive the message.

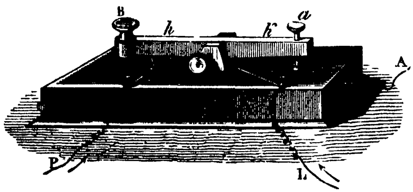


Fig. 491.

The *indicator* or receiver consists of an electromagnet, E, fig. 492, which whenever the current is transmitted attracts an armature of soft iron, *m*, fixed at the end of a lever, *mn*, movable about an axis; when the current is open, the lever is raised by a spring, R. At the other end of the lever there is a pencil, *x*, which writes the signals. For this purpose a long band of strong paper, *ab*, rolled round a drum, S (figs. 489 and 490), passes between two brass rollers with a rough surface, turning in contrary directions. Drawn in the direction of the arrows, the band of paper becomes rolled on a second drum, Q, which is turned by hand. A

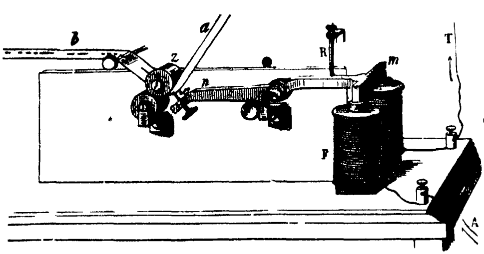


Fig 492.

clockwork motion placed in a box, V, works the rollers between which the band of paper passes.

The paper being thus set in motion, whenever the electromagnet works, the point, x, strikes the paper, and, without perforating it, produces an indentation, the shape of which depends on the time during which the point is in contact with the paper. If it only strikes it instantaneously, it makes a dot (-) ; but if the contact is of any greater duration, a line or dash (—) of corresponding length is produced. Hence by varying the length of contact of the transmitting key at one station, a combination of dots or dashes may be produced at another station, and it is only necessary to give a definite meaning to these combinations.

This is effected as follows in Morse's alphabet :—

	PRINTING.	SINGLE NEEDLE.		PRINTING.	SINGLE NEEDLE.
A	- —	\/	N	— -	/\
B	— - - -	/\\\	O	— — —	///
C	— - — -	/\/\	P	- — — -	\//\
D	— - -	/\\	Q	— — - —	//\/
E	-	\	R	- — -	\/\
F	- - — -	\\/\	S	- - -	\\\
G	— — -	//\	T	—	/
H	- - - -	\\\\	U	- - —	\\/
I	- -	\\	V	- - - —	\\\/
J	- — — —	\///	W	- — —	\//
K	— - —	/\/	X	— - - —	/\\/
L	- — - -	\/\\	Y	— - — —	/\//
M	— —	//	Z	— — - -	//\\

Fig. 493

The other signals are those of the single needle instrument (498). The signal \ denotes a deflection of the top of the vertical needle to the left, and the signal / to the right. They correspond respectively to the dot and dash of the Morse alphabet.

504. **The sounder.**—Any one present while a message is being received at a telegraph station is astonished at the promptitude and accuracy with which signals are read and transmitted by the operators. These acquire such skill that they can read a message by the sounds which the armature makes in striking against the electromagnet of the indicator.

Based on this fact, a form of instrument invented in America has come into use for the purpose of reading by sound. The *sounder*, as it is called, is essentially a small electromagnet on an ebonite base, resembling the relay in fig. 496. The armature is attached to one end of a lever, and is kept at a certain distance from the electromagnet by a spring. When the current passes, the armature is attracted against the electromagnet with a sharp click, and when the current ceases it is withdrawn by the spring. Hence the interval between the sounds is of longer or shorter duration according to the will of the sounder, and thus in effect a series of short and long sounds can be produced, which correspond respectively to the dots and dashes of the Morse alphabet.

505. **Improvements in Morse's telegraph.**—In the apparatus just described, the indentations on the paper only give indistinct

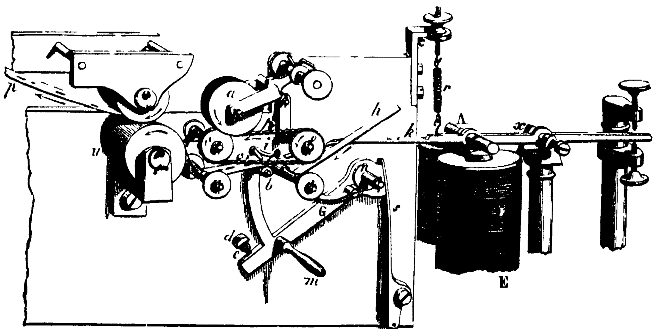


Fig. 494.

dots and dashes, unless the current transmitted be very powerful. To get rid of this inconvenience, and to expend less force, the apparatus has been modified so that the signals can be traced in ink. With this view, all the other parts being the same, the following arrangement is made :—

A roller, ~~a~~, fig. 494, covered with flannel, is moistened with a

suitable ink. Above the roller, and in contact with it, is an endless band, *ph*, rolled on two pulleys, *o*,*o′*, which are turned by the clock-work motion which moves the paper. This is kept by a roller, *b*, very near the chain, but not touching it. That being premised, whenever the current passes in the electromagnet, the armature, A, is attracted, the arm of the lever, *k*, is depressed, and a pin, *i*, at its end rests on the band, and places it in contact with the paper. The band depositing the ink which it has taken from the roller, makes on the paper, as it moves along, a dot or a dash, according to the length of time the current passes, and which dots and dashes have the same meaning as above.

506. **Lightning conductor.**—Besides the parts of the telegraph already described, there are three of which mention must be made: the *lightning conductor*, the *alarum*, and the *relay*.

The influence of storm clouds in decomposing the natural electricity of the wire often produces sufficient tension, not merely to interfere with the transmission of the despatches, but also to produce dangerous discharges. The lightning conductor is intended to remedy these inconveniences.

Represented at M in figs. 489 and 490, it consists of a vertical stand on which are two copper plates, indented like a saw, and arranged so that the teeth are near each other but do not touch. One of these plates is connected with the earth, the other with the line wire. Hence, when, by the inductive action of a storm cloud, electricity accumulates in wires and in the apparatus, it escapes by the points to the plate which is connected with the ground, and thus all danger from a discharge is avoided.

507. **Electrical alarum.**—The electrical alarum is intended to warn the receiving station that a despatch is about to be sent. Represented in fig. 495, it consists of a board on which is fixed an electromagnet by means of a piece of brass, E. The current from the line arriving by a binding screw, *m*, passes to the wire of the electromagnet, thence into the armature, *a*, into a steel spring, *c*, which presses against the armature, and ultimately emerges by a second terminal, *n*.

Thus, whenever the current of the line wire reaches the electromagnet, the armature, *a*, is attracted, and a clapper, P, fixed to this armature, strikes against a bell, T, and makes it sound. The moment the clapper strikes, as the armature is no longer in contact with the spring, C, the current is open, the electromagnet no longer

attracts, and the armature reverts to its original position by the action of a spring, *e*, to which it is fixed.

The current being closed afresh, a second attraction takes place, and so on until the telegraph clerk, thus warned, lets the current pass directly into the receiver without passing through the alarum. This he accomplishes by connecting the terminals *m* and *n* by a short strip of brass by means of an arrangement called a *shunt.*

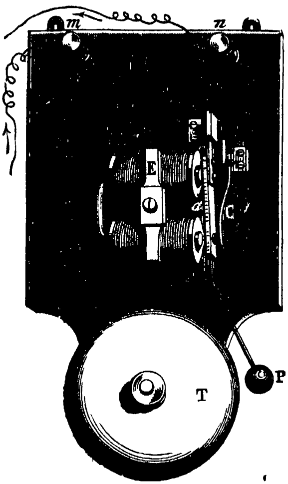


Fig. 495.

Relay. In describing the receiver, we have assumed that the current of the line coming by the line wire, A (fig. 484), entered directly into the electromagnet, and worked the armature, E, producing a despatch; but when the current has to traverse a distance of a few miles, owing to the resistance of the wire and the losses of insulation, its strength is so greatly diminished that it cannot act upon the electromagnet with sufficient force to print a despatch. Hence it is necessary to have recourse to a relay; that is, to an auxiliary electromagnet, which is still traversed by the current of the line, but which serves to introduce into the communicator the current of a *local battery* of four or five elements placed at the station, and only used to print the signals transmitted by the wire

For this purpose the current from the line entering the relay by the binding screw, L (fig. 496), passes into an electromagnet, E, whence it passes into the earth by the binding screw, T. Now, each time that the current of the line passes into the relay, the electromagnet attracts an armature, A, fixed at the bottom of a vertical lever, *p*, which oscillates about a horizontal axis.

At each oscillation the top of the lever, *p*, strikes against a button, *n*, and at this moment the current of the local battery, which enters by the binding screw, *c*, ascends the column, *m*, passes into the lever, *p*, and, by an insulated contact not shown in the figure, descends by the rod, *o*, which transmits it to the binding screw, z; thence it enters the electromagnet of the indicator,

whence it emerges to return to the local battery from which it started, and thus completes the circuit. Thus when the current of the line is open, the electromagnet of the relay, E, does not act, and the lever, *p*, drawn by a spring, *r*, leaves the button, *n*, as shown in the drawing, and the local current no longer passes. Thus the

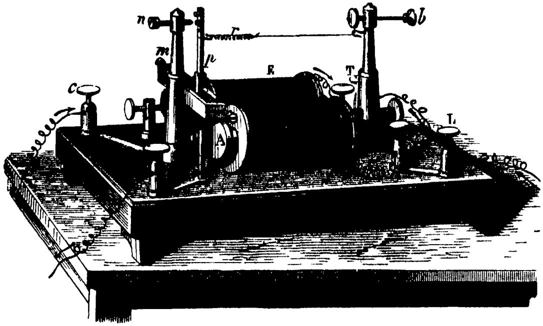


Fig 496.

relay transmits to the indicator exactly the same phases of make and break as those produced by the key in the station which sends the despatch.

508. **Electromagnetic engines.**—Many physicists have attempted to utilise the attractive force of electromagnets as a motive power. Jacobi, of St. Petersburg, appears to have been the first to construct a machine of this kind, with which, in 1838, he moved on the Neva a small boat containing twelve persons. Since that time the construction of these machines has been considerably modified; but in all of them the expense of the zinc and acids which they use far exceeds that of steam engines of the same power; and there is no expectation that electromagnetic engines can be applied at all economically when worked by the voltaic battery.

Fig. 498 represents an electromagnetic engine constructed by Froment. It consists of four electromagnets acting in two couples, on two pieces of soft iron, P, only one of which is seen in the figure. This piece, attracted by the electromagnets, EF, transmits the motion by means of a connecting rod to a crank, *m*, fixed at the end of a horizontal axis. To this is fixed a fly-wheel like that of a steam engine, which is intended to regulate the rotatory

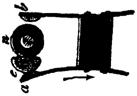


Fig 497

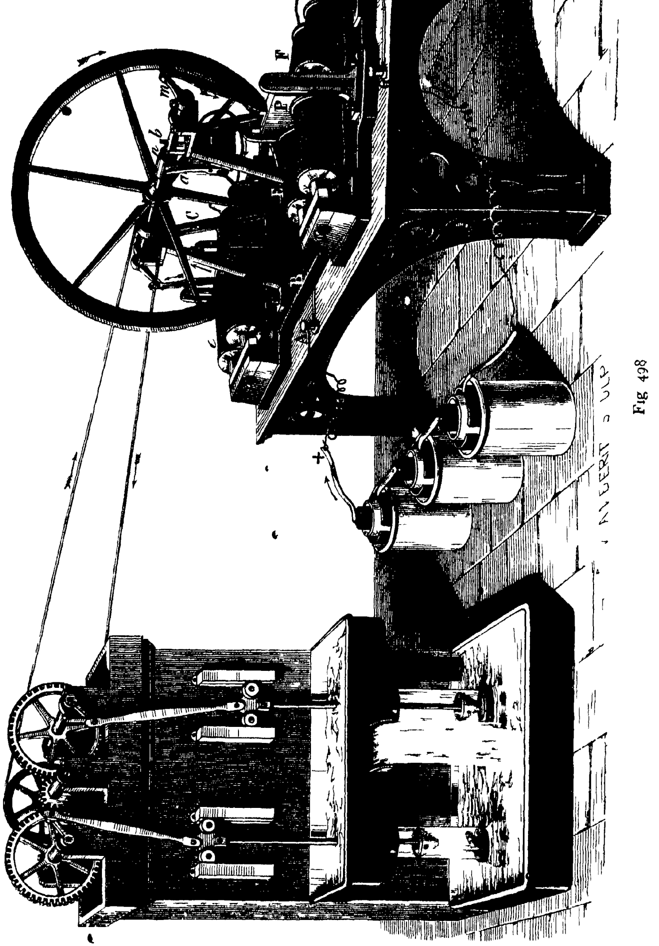


Fig 498

motion. On this axis also is a piece of metal, *n*, of a greater diameter, the action of which will be described presently.

The current of the battery, entering at A, passes into a cast-iron base, B, then by various metallic connections it reaches the metal piece, *n*. Thence the current ought to pass alternately to the first couple of electromagnets, EF, and then to the second, *ef*. In order to understand how this alteration in the path of the current is effected, let us refer to fig. 497 on the right of the picture, which represents a section of the piece, *n*, and its accessories. On this piece is a projection, *e*, which is called a *cam*, and which during a complete turn successively touches two springs, *a* and *b*; these are intended to transmit to the electromagnets the current, the direction of which is indicated by the unfeathered arrows; the arrows do not show the direction of the current, but the direction of the motion of the various pieces of the machine.

These details being known, it will be seen that the current passes alternately into two springs, *a* and *b*, and from thence into the two systems of electromagnets, EF, and *ef*; the piece, P, is first of all attracted, then a similar one, which is placed at the other end of the axis of the fly-wheel. There is thus produced a continuous circulating motion, which is transmitted by an endless band to a train of wheels, which works two lifting pumps, or can be transmitted to any other form of mechanical engine.

CHAPTER XII.

INDUCTION BY ELECTRICAL CURRENTS.

509. **Induction by currents.**—We have already seen (422) that by the term *induction* is meant the action which electrified bodies exert at a distance on bodies in the natural state. Hitherto we have only had to deal with electrostatical induction; we shall now see that dynamical electricity produces analogous effects.

Faraday discovered this class of phenomena in 1832, and he gave the name of *currents of induction* or *induced currents* to

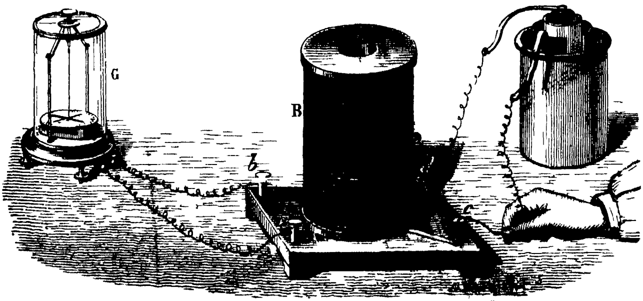


Fig. 499

instantaneous currents developed in metallic conductors by the influence or induction of metallic conductors traversed by electric currents, or by the influence of powerful magnets, or even by the magnetic action of the earth; and the currents which give rise to them he called *induced currents*.

The inductive action of currents at the moment of opening or closing may be shown by means of a coil with two wires. This consists (fig. 499) of a hollow cylinder of wood or of cardboard, on which a quantity of stout silk-covered copper wire is coiled; on this is again coiled a considerably greater length of fine copper wire, also insulated by being covered with silk. This latter coil, which

is called the *secondary coil*, is connected by its ends with two binding screws, *a*, *b*, from which wires pass to a galvanometer, G, while the thicker wire, the *primary coil*, is connected by its extremities with two binding screws, *c* and *d*. One of these, *d*, being connected with one pole of a battery, when a wire from the other pole is connected with *c*, the current passes in the primary coil, and in this alone. The following phenomena are then observed :—

i. At the moment at which the thick wire is traversed by the current, the galvanometer, by the deflection of the needle, indicates the existence in the *secondary coil* of a current *inverse* to that in the primary coil; that is, in the contrary direction : this is only

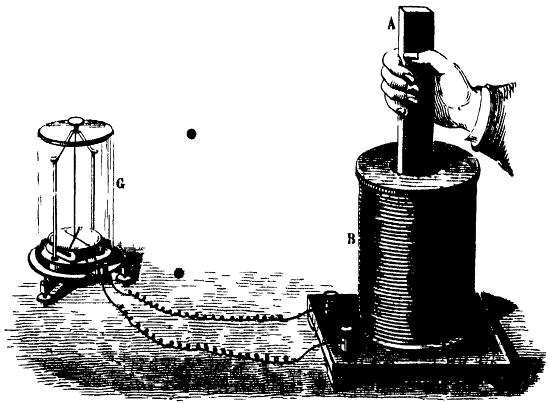


Fig. 500.

instantaneous, for the needle immediately reverts to zero, and remains so as long as the inducing current passes continuously through *ca*.

ii. At the moment at which the current is opened—that is, when the wire *cd* ceases to be traversed by a current—there is again produced in the wire *ab* an induced current, instantaneous like the first, but *direct*; that is, in the same direction as the inducing current.

510. **Induction by magnets and by the action of the earth.** —It has been seen that the influence of a current magnetises a steel bar ; in like manner a magnet can produce induced electrical currents in metallic circuits. Faraday first showed this by means of

a coil with a single wire of 200 to 300 yards in length. The two extremities of the wire being connected with the galvanometer, as shown in fig. 500, one end of a strongly magnetised bar is suddenly inserted in the bobbin, and the following phenomena are observed.

i. At the moment at which the magnet is introduced, the galvanometer indicates in the wire the existence of an *inverse* current; one, that is to say, the direction of which is opposed to that which circulates round the magnet, considering the latter as a solenoid on Ampère's theory (488).

ii. The needle at once returns to zero, and remains there as long as the magnet is in the coil; when it is withdrawn, the needle of the galvanometer, which has returned to zero, now indicates the existence of a *direct* momentary current; that is, one in the opposite direction to the first.

The inductive action of magnets may also be illustrated by the following experiment:—A bar of soft iron, or still better a bundle of soft iron wires, is placed in the above coil, and one pole, N, of a strong magnet is suddenly brought in contact with it; the needle of the galvanometer is deflected, but returns to zero when the magnet is stationary, and is deflected in the opposite direction when it is removed. If the experiment be repeated by introducing the opposite pole, S, the effects will be the same, though the direction of the currents will be the exact opposite. The induction is here produced by the magnetisation of the soft iron bar in the interior of the bobbin under the influence of the magnet.

Faraday discovered that terrestrial magnetism can develop induced currents in metallic bodies in motion; that it acts like a powerful magnet placed in the interior of the earth in the direction of the dipping needle, or, according to the theory of Ampère, like a series of electrical currents directed from east to west parallel to the magnetic equator. He first proved this by placing a long helix of copper wire covered with silk in the plane of the magnetic meridian parallel to the dipping needle; by turning this helix through a semicircle about an axis in its middle, perpendicular to its length, he observed that at each turn a galvanometer, connected with the two ends of the helix, was deflected.

511. **Magnetoelectrical machines.**—If in the experiment described above (510) we had some arrangement by which the magnet, A, could be rapidly and regularly moved in and out of the coil, B, the ends of which were joined either directly or by the inter-

vention of a galvanometer, we should have a series of alternating currents produced in the circuit. The result is the same, if, while the magnet is fixed, the coil is moved towards it—a current will be produced in a particular direction; when the coil is moved away, a momentary current is also produced, but in the opposite direction. Both in this case, and in the experiments described above, the currents are only produced while the relative positions of the coil and the magnet are being altered.

Magnetoelectrical machines are apparatus which are based on these experiments. Fig. 501 represents the essential features of one of the simpler forms, such as is used for medical purposes, and is selected as best suited for illustrating the principle. N S is a horse-shoe magnet firmly fixed in a suitable position—instead of a solid magnet a battery of several magnetic plates is often used—in front of the ends of which are two coils or bobbins of wire, C D, fitted on soft iron cores which are screwed to the soft iron plate, B B. By means of the handle fixed to the axis, A A, these coils can be rotated in front of the poles, N S. The ends of the wires, *mn*, are connected to an arrangement on which press two fork-shaped springs, insulated by a plate of ebonite from each other, and from the magnet to which they are screwed. With these are connected two wires which form the electrodes to which are affixed handles, P and Q.

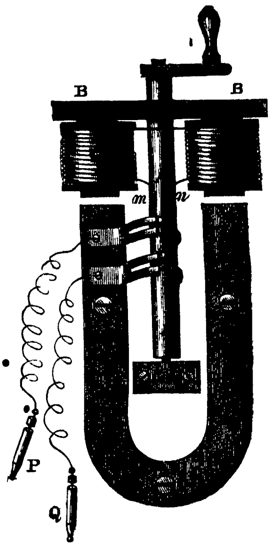


Fig. 501.

Let us first consider that the second bobbin does not exist, or that it is quite inoperative. Then the coil, C, as it rotates, moves upwards from the plane of the paper, and therefore away from N. By so doing the magnetism developed in its core by the induction of the pole, N, diminishes and ceases, the effect of which cessation in the core is to give rise to a direct current in the wire surrounding it. If this coil, continuing its rotation, were to come in front of a second pole of the same kind, N, a current would be induced in it opposite in direction; but, as in the above

case, approaching a pole, S, of the opposite kind, the effect is the same as receding from N. Hence during each half-revolution of the coil, C, a current is produced in a particular direction ; and in the following half-revolution, as it continues to turn from D to C, a current is produced of the same strength but in the opposite direction.

What is true of the one coil, C, is true of the other, D, also ; care is taken that the wire is coiled on the two bobbins in such a manner that the effect in each half-revolution is the same, and thus double the effect is produced.

Hence during a complete revolution of the coils two currents are produced of equal strength but alternately opposite in direction. For some purposes, such as the physiological effects, the heating and the lighting effects, this is of no moment ; but where a continuous current is required, as in electroplating, it is necessary to adjust the currents so that they go in the same direction. This is effected by means of the *commutator* represented on a large scale in fig. 502. On the axis, AA, are four semicircular *half*-rings of metal insulated from each other and from the axis ; the wires, *m* and *n*, from the coils (fig. 501) are connected with these rings, *m* with *a* and *d*, and *n* with *b* and *c*. Now we have seen that the currents in *m* and *n* are alternately positive and negative. When *m* is positive, *a* is positive and *c* is negative ; the contact springs *x* and *y* press on *a* and *c*, and the current travels from *x* to *y*, and so to the electrodes ; but when in the rotation of the coils, C and D, the current is reversed, and *m* is now negative and *n* positive, the spring *x* presses on *b* and *y* on *d*, so that the direction of the current is still from *x* to *y*.

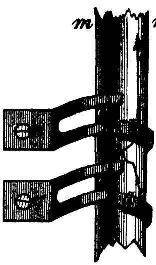


Fig. 502.

511*a*. **Gramme's magnetoelectrical machine.**—An improved magnetoelectrical machine is that invented by Gramme. One form of this apparatus which is designed for lecture purposes is represented on the right-hand side of fig. 503. It consists of a horseshoe magnetic battery, one, that is, consisting of a number of thin steel plates magnetised separately, and then joined together, and provided at the ends with soft iron pieces which form the poles. Between these is a ring-shaped armature or inductor, which is the characteristic feature of the apparatus ; its principle was first discovered by Pacinotti, and is known as *Pacinotti's ring.* It consists

not of a solid ring of soft iron, but of one made by coiling a great length of fine iron wire. Round this is wound at right angles a series of separate coils of insulated wire, which are represented alternately black and white. On the centre of the ring, and rotating with it, is a disc made up of alternate strips of metal and insulator. The coils on the ring form a continuous whole, for the end of each one is joined to one of the metal strips, as is also the beginning of the next. On this disc press flat brushes or bundles of wire, *b b*, which constitute the *collectors*. When the ring is rotated one of the supports of the collecting brushes becomes charged with positive and the other with negative electricity, so that when they are connected by a wire, or by any apparatus (in the figure

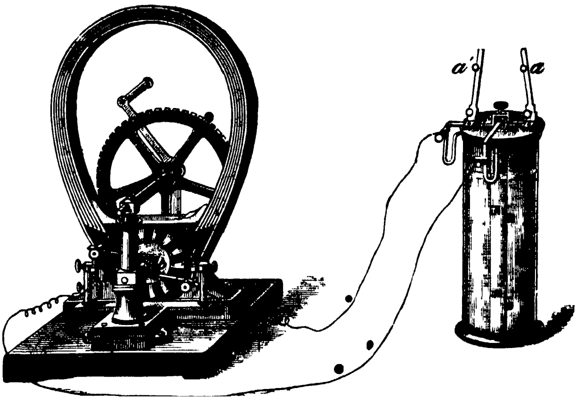


Fig. 503.

it is a secondary battery), a current of electricity is produced which lasts as long as the rotation lasts. These currents are not variable like those of Clarke's machine; they are far more powerful, and are also continuous, that is, they are always in the same direction, and therefore need no commutator. Space cannot here be given for an adequate explanation why the currents are continuous; it is sufficient to say that the various explanations given depend on a consideration of the direction of the Ampèrean currents developed by the permanent magnet in the coils of the inductor in its successive positions while rotating between them.

The currents produced by machines of this class, like that of

any voltaic battery, depend in each case on the ratio of the electromotive force to the resistance (488). The latter depends once for all on the length and diameter of the wire coiled on the ring inductor; the electromotive force depends on the strength of the permanent magnets; and within certain limits it is proportional to the velocity with which the ring is rotated. Such an apparatus as that represented above, when worked by hand, gives a current equal to that of eight Bunsen's cells.

Great improvements have of late years been made in the construction of magnetoelectrical machines; partly by increasing the power and number of the magnets used, partly by increasing the length and number of the coils and modifying the way in which the wire is coiled, and partly, again, by arranging them so that they come more completely within the action of the magnets. Such machines may be worked by water or by steam power, and they furnish the most practical and economical method of producing powerful electric currents. In principle this mode of producing electricity is cheaper than that of voltaic currents; but the electricity produced by magneto-machines and that of voltaic currents both depend in the last resort upon the combustion of coal. In magnetoelectrical machines the coal is directly consumed in working the steam engine which drives the machine; in the battery, coal is used in the metallurgical extraction of zinc. Now it can be shown that the consumption of a given weight of coal in the former case produces more electricity than in the latter.

511*b*. **Electrical transmission of power.**—If the binding screws of two Gramme's machines are connected by wires of even considerable length, and if one of them be rotated, the inductor of the second one rotates with corresponding rapidity. Here the first machine furnishes the current at the expense of the work used in turning it, the second one transforms the current into motion which can again do work. This application is of great importance, as it demonstrates the possibility of transmitting mechanical power to a distance by means of simple metal wires and without the use of wheels, or shafting, or wire ropes, which are the usual modes of transmitting power. But electricity has the important advantage that, as has been proved by actual experiment, power can be transmitted by its means to distances of as much as thirty to forty miles, while the transmission by the ordinary agencies is restricted to far shorter distances.

For the electrical transmission of power three things are

essential—a source of power, which on the large scale would be a gas or steam engine or a water wheel or turbine; a magneto-machine, which is the *exciter*, and a second one in conducting communication with the first, and which is the *motor*; this can do the work which any other motor can do—turn machinery, saw wood, pump water, and the like. The whole of the energy of the mechanical motor does not appear in the electromotor; some of it is transformed into heat in the conducting wires; but it has been found that as much as 50 per cent. of the energy of the motor can be transmitted even through long lengths of wire. This application promises to be of service where natural sources of power are available, such as waterfalls and rivers, and tidal energy. These can be employed to work water wheels, and the power transmitted to where it is to be utilised, and thus, it may be, create new industrial centres.

511*c*. **Dynamoelectrical machines.**—We may imagine in Gramme's machine that we have electromagnets excited by a voltaic battery instead of permanent steel magnets; it will be obvious that since electromagnets are much more powerful than permanent magnets of the same size, the induction currents produced will be more powerful also. Machines in which this principle was applied were devised by Wilde, and far more powerful effects were produced by them than had hitherto been obtained.

A still more important improvement is the following—the principle of which was devised by Sir C. Wheatstone, and by Sir W. Siemens independently. Suppose that, instead of the permanent magnets, we have a horse-shoe-shaped core of soft iron wrapped round with wire, that is, an electromagnet; and suppose further that the wires of this electromagnet are connected with those of an inductor which rotates between the poles of the electromagnet. There is always, even in the best soft iron, a trace of residual magnetism (408) which is sufficient to excite a weak induced current in the inductor as it rotates; this current traverses the wire of the electromagnet, and increases the magnetisation of the core; this augmented magnetism in turn increases the strength of the currents in the inductor, and so this reciprocal action between the inductor and the electromagnet goes on producing an ever-increasing strength of current, which, indeed, in any particular case is only limited by the speed with which the inductor can be rotated. Machines based on this principle, which transform work into electrical currents,

are called *dynamoelectrical*, or more briefly *dynamomachines*, in contradistinction to *magnetoelectrical* machines, in which permanent magnets are used. Both are, however, strictly speaking, dynamomachines, for the electricity is in both cases produced at the expense of work.

Fig. 504 represents the essential features of one of the small-sized vertical machines of this kind made by Messrs. Siemens. A characteristic is the *cylindrical* or *drum armature*. The electro-magnets MM and M′M′ with double poles feed the magnetism of the soft iron armatures N, which are bent so as to almost completely encircle the inductor; they are in detached pieces, so that air can freely circulate between them, and thereby the temperature be kept down.

The inductor itself, D, consists of a drum-shaped frame of soft iron wire covered with a layer of insulating material, and fixed to an axle which rests in the strong upright supports, and is rotated by means of power transmitted to the sheave A. The wire is coiled on this; one end is attached to a plate which forms part of the collector, as in Gramme's machine (511*a*); it passes lengthwise round the drum in several turns, and the other end is attached to a similar piece on the collector, which is diametrically opposite the first. The wire is continuous, the connection of the individual strands being effected by means of the collector. On the collectors rest two pairs of brushes; they are connected respectively with insulated binding-screws; from these the current passes through the wires of the electro-magnet, and thence to the terminals, *p p*, where it may be utilised in the external circuit.

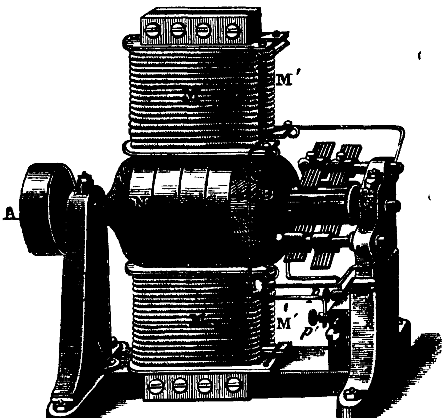


Fig. 504.

The advantage of this construction is that from the length of the inductor, and from the wires being on its surface and quite close

to the armatures of the magnets, the influence of the latter is greater.

A small machine of this kind, which does not occupy a space of more than three cubic feet, and rotating with a velocity of 15 turns in a second, which is effected by 1½ horse power, can produce a light of 1,400 candles. The larger sizes produce far more powerful effects, but require of course greater power to work them. They are however relatively more economical.

511*d*. **Electrical accumulators.**—We have hitherto been concerned with the production of electricity by the voltaic battery, and by magnetoelectrical machines; the chemical decompositions effected by the passage of the current (478) put into our hands a means of storing or accumulating electricity. For when two plates of platinum placed in dilute sulphuric acid are connected with the poles of a battery, and are then detached from the battery, and connected with any arrangement for showing the passage of the electrical current, it will be seen that such a current is produced, but its direction is opposed to that of the original current. Currents thus produced are called *secondary currents* (470), and the phenomenon is sometimes known as that of the *polarisation of the electrodes*. By the passage of the current the ultimate products of chemical decomposition, in the above case oxygen and hydrogen, are accumulated on the two electrodes, so that when the plates are disconnected from the battery the gases are in a condition in which they can readily unite with each other, and by their union re-form water. Thus it is not an accumulation of electricity which is here produced, but an accumulation of the bodies resulting from the chemical separation which the flow of electricity can effect, and which by their recombination produce the electrical current.

On the right-hand side of fig. 504 is a representation of an element constructed on these principles, known as *Planté's battery*, and is the first in which this principle, originally discovered by Ritter, was successfully employed. It consists of two plates of lead rolled in a spiral and separated by felt or some other nonconductor; the liquid in which it is immersed is dilute sulphuric acid. By means of wires these plates can be connected up with those conveying the electrical current, and there is also a simple arrangement by which the connection of the plates with the charging battery may be broken, and the secondary current utilised just as any other current would be.

The general nature of the action in charging the accumulator is

that the oxygen liberated at the positive plate converts the surface into peroxide of lead, while hydrogen is set free on the negative plate; when the current of the battery is reversed, the peroxide is reduced to metallic lead, which however is in a spongy state, while the other plate is now covered with peroxide. By repeating this process the surface of both plates ultimately acquires this spongy texture, which enables much more of the gases to be condensed on their surface, and thereby renders them much more powerful.

So long as the only practical source of electrical currents was the voltaic battery, the use of such accumulators could only extend to the case of laboratory or lecture experiments; but the question entered on a new phase when the great improvements in magneto-electrical machines showed that they furnished a means of producing powerful electrical currents at the expense of mechanical power. By connecting an accumulator with a magnetoelectrical machine, as represented in fig. 503, it is possible to store up the products of chemical separation in a form in which they are available at any moment for the production of electrical currents. So far, the expectations, at first held out, that these *storage* batteries would retain their charge for an unlimited time have not been realised; there is always a certain amount of leakage, and the charge gradually runs down. But it may reasonably be hoped that the main difficulties in this direction will be overcome, and then the principle will be most fruitful in its applications.

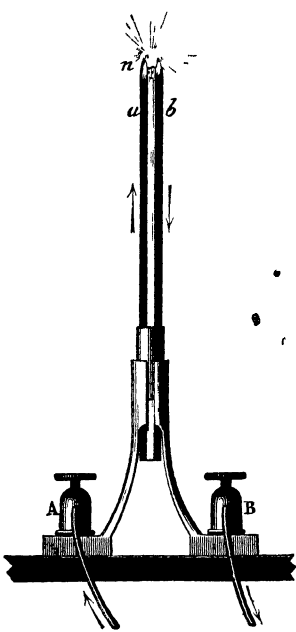


Fig. 505.

512. **Electrical candle.**—The extended use of the electric light was one of the first results to follow on the improvements which have been made in magnetoelectrical machines. A chief element in the production of the electric light is, as we have seen, the nature of the candle or lamp (477). One of the simplest is that known as the *Jablochkoff candle*, which does not require the complicated mechanism of the arc

lights. It consists (fig. 505) of two thin rods, *a b*, of the graphitoidal carbon obtained from the inside of gas retorts (473), placed near and parallel to each other, but separated by a thin layer of *kaolin*, a kind of decomposed felspar, so as to insulate them from each other. This is fixed in a suitable support, and one of the rods is in metallic connection with the binding screw A, and the other with B.

When the wires from a magnetoelectrical machine are connected with A and B, and the machine is set to work, the voltaic arc is produced at *n* between *a* and *b*, and the heat is so great as to fuse, and even volatilise, the insulating layer, which thus wears away, as do the carbons. Now we have seen that in the voltaic arc the positive pole wears away faster than the negative one; the end *a* would thus wear away much faster than *b*, and the distance between them increasing, the current would stop. This is prevented by the use of alternating currents—that is, there is no commutator in the machine; the parts corresponding to *x* and *y* (fig. 502) are in contact with *rings* with which the wires *m* and *n* are connected. Thus *a* and *b* are each alternately positive and negative, and, the carbons wearing away equally fast, the light remains constant until the candle is completely burnt away.

A magnetoelectrical machine not weighing more than three hundredweight, worked by steam power, has been found to produce a light equal to 1,250 candle power (317) for each horse power (273) of mechanical energy. Assuming that each horse power is kept up at an expenditure of three pounds of coal in an hour, that would represent a light of 417 candles for one hour for an expenditure of one pound of coal.

Now it is found that a consumption of 140 cubic feet of gas of 18 candle power is required for the production of a light of the same brilliancy in the same time. For the manufacture of such an amount of gas of this quality, thirty pounds of coal are needed, and, assuming that 50 per cent. of the value of the coal is returned in the form of gas coke and other products, there is still an expenditure of fifteen pounds of coal in the one case, as against one pound in the other.

513. **Ruhmkorff's coil.**—This is an arrangement for producing induced currents, in which a current is induced by the action of a voltaic current, whose circuit is alternately opened and closed in rapid succession. These instruments, known as *inductoriums* or *induction coils*, present considerable variety in their construction, but all consist essentially of a hollow cylinder in which is a bar of

soft iron, or bundle of iron wires, with two helices coiled round it, one connected with the poles of a battery, the current of which is alternately opened and closed by a self-acting arrangement, and the other serving for the development of the induced current. By means of these apparatus, physical, chemical and physiological effects are produced with a current of three or four Grove's cells, equal to and superior to those obtainable with electrical machines and even the most powerful Leyden batteries.

Of all the forms of induction coils, those constructed by Ruhmkorff in Paris, and by Ladd and Apps in this country, are the most powerful. Fig. 506 is a representation of one the coil of which is about 14 inches in length. The *primary* or *inducing* wire is of copper, and is about 2 mm. in diameter and 4 or 5 yards in length. It is coiled directly on a cylinder of cardboard, which forms the nucleus of the apparatus, and is inclosed in an insulating cylinder of glass or of ebonite. On these is coiled the secondary or induced wire, which is also of copper, and is about $\frac{1}{3}$ mm. in diameter. A great point of these apparatus is the insulation. The wires are not merely insulated by being in the first case covered with silk, but each individual coil is separated from the rest by a layer of melted shellac. The length of the secondary wires varies greatly; in some of the largest sizes it is as much as two or three hundred miles. With these great lengths the wire is thinner, about $\frac{1}{5}$ mm.

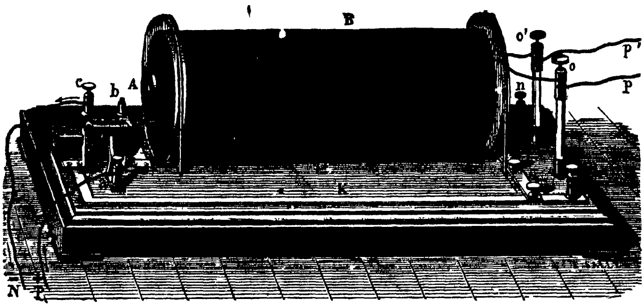


Fig. 506.

The following is the working of the apparatus. The current arriving by the wire, P, at a binding screw, *a*, passes thence into the commutator, C (fig. 506); thence by the binding screw, *b*, it enters

the primary wire, where it acts inductively on the secondary wire; having traversed the primary wire it emerges by the wire, *s* (fig. 507). Following the direction of the arrows, it will be seen that the current ascends in the binding screw, *i*, reaches an oscillating piece of iron, *o*, called the *hammer*, descends by the *anvil*, *h*, and passes into a copper plate, K, which takes it to the commutator, C. It goes from thence to the binding screw, *c*, and finally to the negative pole of the battery by the wire, N (fig. 506). The current in the primary wire only acts inductively on the secondary wire (509) when it opens or closes, and hence it must be constantly interrupted. This is effected by means of the oscillating hammer, *o*, omitted in fig. 506, but represented on a larger scale in fig. 507. In the centre of the bobbin is a bundle of soft iron wires forming together a cylinder a little larger than the bobbin, and thus projecting at the end as seen at A. When the current passes in the primary wire this hammer, *o*, is attracted; but immediately, there being no contact between *o* and *h*, the current is broken, the magnetisation ceases, and the hammer falls; the current again passing, the same series of phenomena recommences, so that the hammer oscillates with great rapidity.

In proportion as the current passes thus intermittently in the primary wire of the bobbin, at each interruption an induced current, alternately direct and inverse, is produced in the secondary wire. But as this is perfectly insulated, the current acquires such an intensity as to produce very powerful effects. Fizeau increased this intensity by interposing a *condenser* in the induced circuit. As constructed by Ruhmkorff, for his largest apparatus, it consists of 150 sheets of tinfoil about 18 inches square; these sheets being joined are coiled on two sides of a sheet of oiled silk, which insulates them, forming thus two armatures; they are then coiled several times round each other, so that the whole can be placed below the helix in the base of the apparatus. One of these armatures, the positive, is connected with the binding screw, *i*, which receives the current on

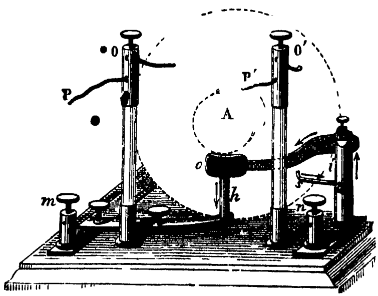


Fig. 507.

emerging from the bobbin; and the other, the negative, is connected with the binding screw, *m*, which communicates by the plate, K, with the commutator, C, and with the battery.

514. **Effects produced by Ruhmkorff's coil.**—The high degree of tension which the electricity of induction coil machines possesses has long been known, and many luminous and calorific effects have been obtained by their means. But only since the improvements which have been introduced into these coils has it been possible to utilise all the tension of induced currents, and to show that these currents possess powerful statical as well as dynamical effects.

Induced currents are produced in the coil at each opening and breaking of contact. But these currents are not equal either in duration or in tension. The direct current, or that on *opening*, is of shorter duration but higher tension; that of *closing*, of longer duration but lower tension. Hence if the two ends, P and P′, of the fine wire (figs. 506 and 507) are connected, as there are two equal and contrary quantities of electricity in the wire, the two currents neutralise each other. If a galvanometer is placed in the circuit, only a very feeble deflection is produced in the direction of the direct current. This is not the case if the two extremities, P and P′, of the wire are separated. As the resistance of the air is then opposed to the passage of the currents, that which has higher tension, that is, the direct one, passes in excess, and the more so the greater the distance of P and P′, up to a certain limit, at which neither passes. There are then at P and P′ nothing but tensions alternately in contrary directions.

The effects of the coil, like those of the battery, may be classed under the heads *physiological*, *chemical*, *heating*, *luminous*, *mechanical*; they differ from those of the battery in being enormously more intense.

The *physiological* effects of Ruhmkorff's coil are very powerful, in fact the shocks are so violent that many experimenters have been suddenly prostrated by them. A rabbit may be killed with an induction current arising from two of Bunsen's elements, and a somewhat larger number of couples would kill a man.

The *heating* effects are also easily observed; it is simply necessary to interpose a very fine iron wire between the two ends, P and P′, of the induced wire; this iron wire is immediately melted, and burns with a bright light. The spark of the Ruhmkorff's coil has been used to fire mines in military and mining operations.

The *chemical* effects are very varied, inasmuch as the apparatus produces both the ordinary effects of the current and of electricity in a high state of tension. Thus, according to the shape and distance of the platinum electrodes immersed in water, and to the degree of acidulation of the water, either luminous effects may be produced in water without decomposition, or the water may be decomposed and the mixed gases disengaged at the two poles, or again the decomposition may take place, and the mixed gases separate either at a single pole or at both poles.

The *luminous* effects of Ruhmkorff's coil are also very remarkable, and vary according as they take place in air, in vacuo, or in very rarefied vapours. In air the coil produces a very bright loud spark, which, with the largest sized coils, has a length of eighteen inches. In vacuo the effects are also remarkable. The experiment is made by connecting the two wires of the coil, P and P′, with the two rods of the electrical egg (fig. 405), used for producing in vacuo the luminous effects of the electrical machine. A vacuum having been produced, a beautiful luminous trail is produced from one knob to the other, which is virtually constant, and has an intensity similar to that obtained with a powerful electrical machine when the plate is turned.

If this light be closely observed, it will be found that if some vapour of turpentine, or wood spirit, or bisulphide of carbon, have been introduced into the globe before exhaustion, instead of being continuous, the light consists of a series of alternately dark and bright zones, forming a pile of electric light between the two poles. This phenomenon is known as the *stratification of the electric light*, and due to the circumstance that the current is discontinuous.

The brilliancy and beauty of the stratification of the electric light are most remarkable when the discharge of the Ruhmkorff's coil takes place in glass tubes containing a highly rarefied vapour or gas. These phenomena, which have been investigated by Masson, Grove, Gassiot, Plücker, etc., are produced by means of sealed glass tubes, first constructed by Geissler, of Bonn, and known as *Geissler's tubes*. These tubes are filled with different gases or vapours, and are then exhausted. At the ends of the tubes two platinum wires are soldered into the glass. See figures on the right and left in the coloured plate at the beginning of this book.

When the two platinum wires are connected with the ends of a Ruhmkorff's coil, magnificent lustrous striæ, separated by dark bands, are produced all through the tube. These striæ vary in

shape, colour, and lustre with the degree of the vacuum, the nature of the gas or vapour, and the dimensions of the tube. The phenomenon has occasionally a still more brilliant aspect from the fluorescence which the electric discharge excites in the glass.

The figure on the right (coloured plate) represents the appearance presented by hydrogen; in the bulbs the light is a pale lavender blue, in the capillary parts it is red.

In carbonic acid the colour is greenish, and the striæ have not the same shape as in hydrogen; in nitrogen, as represented in the figure on the left, the light is reddish violet. In chlorine the colour

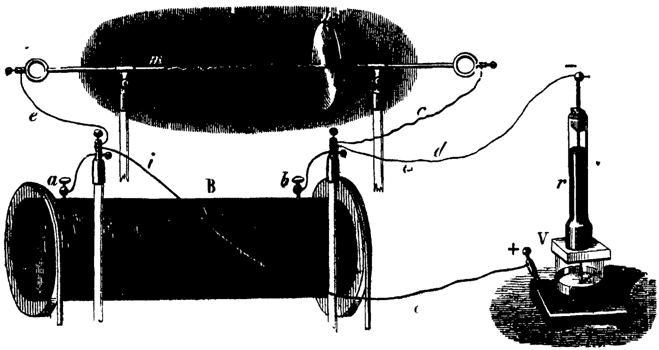


Fig. 508.

is reddish violet in the wide part of the tube, and in very narrow tubes green.

Mechanical effects. By means of Ruhmkorff's coil mechanical effects can also be produced, so powerful that, with the largest apparatus, glass plates two inches thick have been perforated. The result, however, is not obtained by a single discharge, but by several successive discharges.

The experiment is arranged as shown in fig. 508. The two poles of the induced current correspond to the binding screws, *a* and *b*; by means of a copper wire, *i*, the pole, *a*, is connected with the lower part of an apparatus for piercing glass like that already described (fig. 426), the other pole is attached to the upper conductor by a wire, *d*. This conductor is insulated in a large glass tube, *r*, filled with shellac, which is run in while in a state of fusion. Between the two conductors is the glass to be perforated, V. When this presents too great a resistance, there is danger lest the spark pass

in the coil itself, perforating the insulated layer which separates the wire, and then the coil is destroyed. To avoid this, two wires, *e* and *c*, connect the poles of the coil with two metal rods, *m* and *n*, whose distance from each other can be regulated. If then the spark cannot penetrate through the glass, it bursts across with a bright spark and a loud report, and the coil is not injured.

515. **Rotation of induced currents by magnets.**—De la Rive devised an experiment which shows in a most beautiful manner that magnets act on the light in Geissler's tubes in accordance with the laws with which they act on any other movable conductor.

On the iron core of an electromagnet, M (see coloured plate), is a soft iron rod terminated at the top by an iron plate; this rod, with the exception of the top, *a*, is inserted in a very carefully insulated glass tube. The binding screw, *k*, is in conducting communication with this iron rod. The whole of the upper part of this arrangement is fitted into the tubulure of an electrical egg; with which the brass tubulure, *dd*, which holds the glass tube, is in conducting communication. By the stop-cock at the top the electrical egg can be exhausted, and a few drops of alcohol are then introduced.

If now the wires from a Ruhmkorff's coil are connected with the binding screws, *h* and *k*, but without at the same time exciting the electromagnet, a more or less irregular luminous sheaf passes from the plate, *a*, to the ring, *dd*.

But if a voltaic current passes into the electromagnet, the phenomenon is different; instead of starting from different points of the upper surface and the ring, the light is condensed and emits a single luminous arc. Further, and this is the most remarkable part of the experiment, this arc turns slowly round the magnetised cylinder, sometimes in one direction and sometimes in another, according to the direction of the induced current, or the direction of the magnetisation evoked in the core. As soon as the magnetisation ceases, the luminous phenomenon reverts to its original appearance.

This experiment is remarkable as having been devised *à priori* by De la Rive to explain by the influence of terrestrial magnetism, a kind of rotary motion from east to west, observed in the aurora borealis. The rotation of the luminous arc in the above experiment can evidently be referred to the rotation of currents by magnets (493).

516. **The Telephone.**—We have already described an instrument in which communications are made through a wire connecting

two distinct stations by means of the sound produced by the attractions of an armature against an electromagnet (504). Here, though the sounds are all of the same kind, they may be varied in duration, and, by the suitable combination of short and long sounds, it is possible to produce signals at a distant station which have a perfectly definite meaning.

An instrument has of late been invented which is far in advance of this: and whether we look at the simplicity of its principle and of its construction, or at the importance and practical utility of the results already obtained by its means, or again at its promise in the future, it must surely be regarded as one of the most surprising of modern inventions. By its means it is possible not merely to produce sound at a distance, but to produce articulate sounds; to speak audibly, or to send a musical air through a circuit of many miles of ordinary telegraph wire.

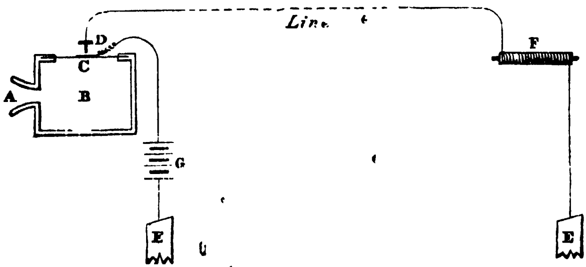


Fig. 509.

Reis in 1862 was the first to make a successful attempt to transmit musical sounds to some distance by means of electricity. The general plan of the apparatus which he used is represented in fig. 509. It consisted essentially of a hollow box, B, fig. 509, in one of the sides of which is a mouthpiece, A, while another is closed by a thin membrane. On this membrane is a piece of thin metal foil, C, which is connected with a wire leading to one pole of a battery, G, the other pole of which is put in connection with the earth. Just above the foil, and almost touching it, is adjusted a metal point, D, which is connected by the line wire (500), with one end of a spiral coil of insulated wire, F, surrounding an iron rod, the other end of which is put to earth (501).

The production of sound depends on an observation made

by Page, that when an iron rod surrounded by a spiral of insulated wire is rapidly magnetised and demagnetised, by the intermittent passage of an electrical current, a musical sound is produced which is strengthened by the spiral being placed on a sounding-board.

Now the sounds produced by speaking or singing into the mouthpiece set the membrane in vibration; this alternately opens and closes the current, and these makes and breaks in the current being transmitted through the circuit to the electromagnet, F, produce the sound.

The telephone to be described is characterised by far greater simplicity and efficiency, and also by its requiring no electrical battery. It is the invention of Professor Graham Bell, of Boston. Omitting any reference to the successive improvements which have been made in the instrument until its present very simple form has been adopted, we may describe it at once. It is represented in something less than half its ordinary size in fig. 510, while fig. 511 gives the details of the construction.

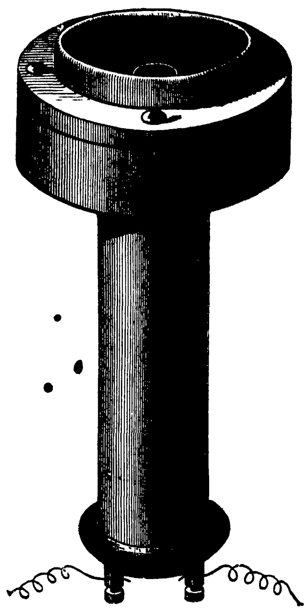


Fig. 510.

It consists essentially of a steel magnet, M, about four inches in length and about half an inch wide, inclosed in a wooden case. Round one end of this magnet is fitted a thin flat coil, BB, of fine insulated copper wire, the ends of which coil pass through longitudinal holes, LL, in the case, and are connected with the binding screws, CC. In front of the magnet, and at a distance which can be regulated by a screw, S, but which is something less than a millimetre, is the essential feature of the instrument, a diaphragm, D, of soft iron, not much thicker than a sheet of stout letter-paper. This diaphragm is screwed down by the mouthpiece, E, which is similar to, though somewhat larger than, that of a stethoscope.

The instruments are connected by wires, for one of which the earth may be substituted, as in ordinary telegraphic communication (501). Each instrument can be used either as sender or receiver, though in actual practice it is more convenient for each operator to have two telephones, one of which is held to the ear, while the other is used for speaking into.

The action of the instrument depends on the fact that whenever the relative positions of a magnet and of a closed coil of wire are altered (510), there is produced within the coil a current or currents of electricity. This may be illustrated by reference to fig. 500. When the magnet is suddenly brought into the coil a current is produced in the coil in a particular direction. There is no current so long as the coil and the magnet are stationary. When, however, the

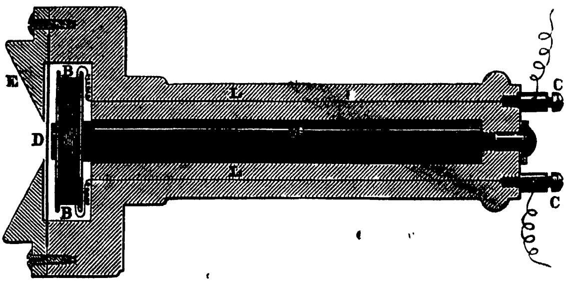


Fig. 511.

magnet is suddenly withdrawn, a current is produced in the opposite direction. Similar effects are produced if, while the magnet is in the coil, its magnetism is by any means increased or diminished.

Now in the telephone the magnet and the coil, when once properly adjusted, remain fixed. But the magnet, M, magnetises by induction the soft iron membrane, D, in front of it, that is, converts it into a magnet. When by the mouthpiece being spoken into this iron membrane vibrates backwards and forwards, these vibrations give rise to an alteration in the magnetic condition of the permanent magnet, the effect of which is that currents are produced in alternate directions in the coil surrounding the pole. Moreover, the alternation in the relative positions of the magnetised diaphragm, and of the coil, give rise to currents in the same direction as the above. These alternating currents being transmitted through the circuit to the distant coil, alternately attract and

cease to attract the corresponding diaphragm. They thereby put this in vibration, and when the mouthpiece of this telephone is held to the ear, these vibrations are perceived as sound, precisely corresponding to that which is transmitted. Hence whatever sound produces the vibration of the diaphragm of the sending instrument is repeated by the second, for its vibrations are exactly reproduced.

Although the reproduction of the sound in the receiving instrument is perfect as far as articulation is concerned, it is considerably enfeebled. The sound has something of a metallic character, and appears as if heard through a long length of tubing. It is only perceived by the person using the telephone as a receiver, and he must hold the mouthpiece close to the ear. Hence in order to attract attention at the distant station, an electrical alarum worked by a magnetic electrical machine, and suitably connected in the circuit, is used as a call. It is to be hoped that some means will be found by which the sound may be strengthened so as to be audible to a whole room. It is difficult to work the instrument on a busy line of telegraphic communication where there are several wires. The electrical currents passing in the adjacent wires, and even the vibrations of these wires against the posts on which they rest, produce a continual vibration in the telephone circuit, so that when, under these circumstances, a telephone is held close to the ear, a continuous noise, like the pattering of hail, is heard, which destroys the sound of direct speech. This may, however, be eliminated by having the telephonic circuit of two wires twisted close together, one of them used for going and the other for returning; as they are both at the same distance from the extraneous cause, whatever this may be, its effects are equal and in opposite directions; they therefore neutralise each other. The limit of power of the instrument has yet to be ascertained. In India it has been found possible to speak audibly through a distance of 500 miles, and even breathing has been heard through a distance of 150 miles. Signals have been sent by its means through the submarine cable between Dover and Calais, and also between Dartmouth and Guernsey, a distance of 60 miles.

If while a musical box is being played, the mouthpiece of the telephone is placed upon it, or if the mouthpiece of the instrument be held over an open pianoforte, the music in each case is reproduced at the receiving instrument.

The telephone has been applied, with success, to speak with

divers when under water. It has also been used for scientific investigations as a galvanometer; it reveals the existence of currents so feeble as to be without action on even the most delicate forms of the ordinary instruments. Experiments made to test its applicability for military purposes are of great promise, and altogether the instrument—the capabilities of which are but beginning to be known —has, without doubt, a great future before it.

516*a*. **Microphone.**—This instrument, invented by Professor Hughes, derives its name from the fact that it renders sounds audible which to ordinary ears are quite inaudible. Its construction is of great simplicity: fig. 512 represents the form in which it

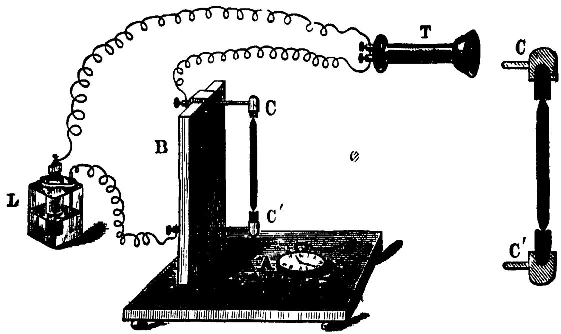


Fig. 512.

was first made by its inventor, Professor Hughes. Fixed to a small upright of light wood, B, resting on a base of the same material, A, are two binding screws which terminate in two brass caps, C C′, enclosing pieces of gas graphite. A piece of this substance rests loosely in the cavities in the manner represented on a larger scale in the figure on the side. When this apparatus is connected up with a battery and a telephone, T, as shown in the figure, the faintest sound produced on the base, the ticking of a watch, the scratching of a pen, or even the creeping of a fly, are distinctly audible in the telephone. The action of the instrument appears to be that when two imperfect conductors, forming part of a voltaic circuit, are in loose contact, any variation in their degree of contact produced by vibration produces a change in the resistance, and this change at once varies the strength of the current in a corresponding way, and these variations produce exactly

corresponding vibrations in the telephone by which they are heard.

To obtain the best results with a particular instrument, the position of the carbon must be carefully adjusted by trial; and indeed the form of the instrument itself must be variously modified for the special object in view: in some cases great sensitiveness is required; in others great range. In order to eliminate as far as possible the effect of accidental vibrations due to the supports, the base should rest on pieces of vulcanised tubing, or on wadding.

The *microphone transmitter*, now in such frequent use, consists of a sort of frame in which is a thin plate of ebonite; on the back of this is a microphone connected up with a telephone and element, as above shown. When the voice is directed against this plate, it is thereby set in vibration, and these vibrations varying the strength of the current are transmitted to the telephone, which then produces the exact words and even the intonation.

CHAPTER XIII.

THERMOELECTRIC CURRENTS.

517. **Thermoelectricity.**—In 1821 Professor Seebeck, in Berlin, found that by heating one of the junctions of a metallic circuit, consisting of two metals soldered together, an electric current was produced. This phenomenon may be shown by means of the

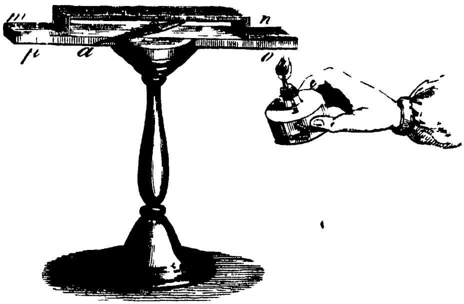


Fig. 513.

apparatus represented in fig. 513, which consists of a plate of copper, *mn*, the ends of which are bent and soldered to a plate of bismuth, *op*. In the interior of the circuit is a magnetic needle, *a*, oscillating on a pivot. When the apparatus is placed in the magnetic meridian, and one of the solderings gently heated, as shown in the figure, the needle is deflected in a manner which indicates the passage of a current from *n* to *m*, that is, from the heated to the cool junction in the copper. If, instead of heating the junction, *n*, it is cooled by ice, or by placing upon it cotton-wool moistened with ether, the other junction remaining at the ordinary temperature, a current is produced, but in the opposite direction : that is to say, from *m* to *n*. In both cases the current is more energetic in proportion as the *difference* in temperature of the solderings is greater.

Seebeck gave the name *thermoelectric* to this current, and the couple which produces it, to distinguish it from the *hydroelectric* or ordinary voltaic current and couple.

518. **Thermoelectric series.**—If small bars of two different metals are soldered together at one end, while the free ends are connected with the wires of a galvanometer, and if now the point of junction of the two metals be heated, a current is produced, the direction of which is indicated by the deflection of the needle of the galvanometer, fig. 514. By experimenting in this way with different metals, they may be formed in a list such that each metal gives rise to positive electricity when associated with one of the following, and negative electricity with one of those that precede; that is, that in heating the soldering, the positive current goes from the positive to the negative metal across the soldering, just as if the soldering itself represented the liquid in a hydroelectrical element; hence out of the element, in the connecting wire in the

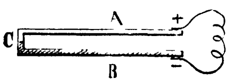


Fig. 514.

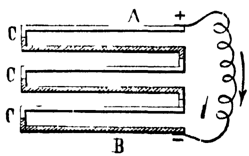


Fig. 515.

galvanometer for instance, the current goes from the negative to the positive metal. Thus a couple, bismuth-antimony, heated at the junction would correspond to a couple, zinc-copper, immersed in sulphuric acid. Fig. 515 represents a battery of such elements.

Of all bodies, bismuth and selenium produce the greatest electromotive force; but from the expense of this latter element, and on account of its low conducting power, antimony is generally substituted. The antimony is the negative metal but the positive pole, and the bismuth the positive metal but the negative pole, and the current goes from bismuth to antimony across the junction.

519. **Nobili's thermoelectric pile.**—Nobili devised a form of thermoelectric battery, or pile as it is usually termed, in which there are a large number of elements in a very small space. For this purpose he joined the couples of bismuth and antimony in such a manner that, after having formed a series of five couples, as represented in fig. 516, the bismuth from *b* was soldered to the

antimony, of a second series, arranged similarly; the last bismuth of this to the antimony of a third, and so on for four vertical series, containing together twenty couples, commencing by antimony, finishing by bismuth. The couples thus arranged are insulated from one another by means of small paper bands covered with varnish, and then inclosed in a copper frame, P (fig. 517), so that only the solderings appear at the two ends of the pile. Two small binding screws, *m* and *n*, insulated by an ivory ring, communicate in the interior, one with the first antimony, representing the positive pole, and the other with the last bismuth, representing the negative pole. To these binding screws are connected the extremities of a galvanometer wire, when the thermoelectric current is to be observed.

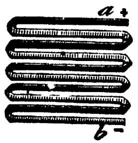


Fig. 516.

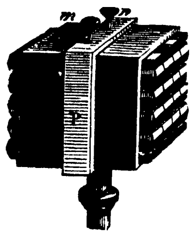


Fig. 517.

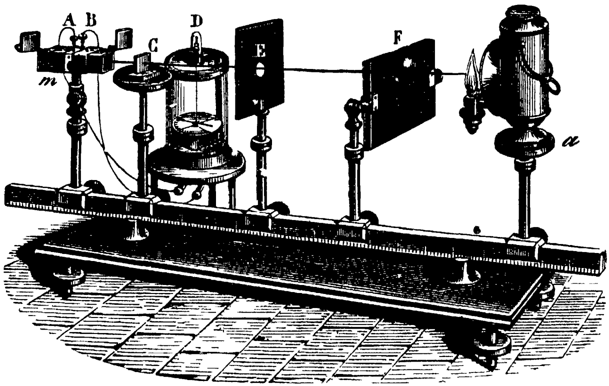


Fig. 518.

A Nobili's pile in combination with a galvanometer constitutes the most delicate and accurate means of measuring temperatures. Such an arrangement was first used by Melloni in his researches on the transmission of radiant heat (221). The arrangement he used is represented in fig. 518.

On a wooden base, provided with levelling screws, a graduated brass rule, about a yard long, is fixed edgeways. On this rule the various parts composing the apparatus are placed, and their distances can be fixed by means of binding screws. *a* is a support for a Locatelli's lamp, or other source of heat; F and E are screens; C is a support for the bodies experimented on, and *m* is a thermo-electrical battery. Near the apparatus is a galvanometer, D, which has only a comparatively few turns of a tolerably thick (1 mm.) copper wire. Such galvanometers are called *thermomultipliers* (487). The delicacy of this apparatus is so great that the heat of the hand is enough, at a distance of a yard from the pile, to deflect the needle of the galvanometer.

520. **Properties and uses of thermoelectric currents.**—The electromotive force of thermoelectric currents is very low, but they are of great constancy; for their opposite junctions, by means of melting ice and boiling water, can easily be kept at 0° and 100° C. On this account, Ohm used them in the experimental establishment of his law (488). They can produce all the actions of the ordinary battery in kind, though in less degree. By means of a thermoelectric pile consisting of 769 elements of iron and German silver, the ends of which differed in temperature by about 10° to 15°, Kohlrausch proved the presence of free positive and negative electricity at the two ends of the open pile respectively, and also found that the electromotive force of a single element under the above circumstances was about $\frac{1}{6000}$ that of a single Daniell's element. Thermoelectric piles produce only feeble chemical actions. Botto, however, with 120 platinum and iron wires, decomposed water.

APPENDIX *of* QUESTIONS.

I.—GENERAL PROPERTIES OF MATTER AND UNIVERSAL ATTRACTION.

1. What is the difference between a chemical and a physical action? Give some examples of each.

2. What are the three forms in which matter exists?

3. By what properties of the molecules do we account for the existence of matter in three different forms?

4. Give instances of one and the same body being met with in the three different forms which matter assumes.

5. State and explain what is meant by inertia.

6. Explain the meaning of the terms (*a*) uniform motion; (*b*) uniformly accelerated motion; (*c*) retarded motion; and state how such effects are produced.

7. What effect on the motion of a ship is produced according as the bow or the stern guns are fired?

8. Give an accurate explanation of the process of freeing a carpet from dust by beating it with a stick.

9. Give instances of cases in which it is desired to increase friction; and others in which it is diminished.

10. Give some examples of rolling friction, and some of gliding friction.

11. Why is the bob of a pendulum thinner at the edge than in the middle?

12. How can it be shown that a coin and a feather fall with equal velocity?

13. In rowing, what is the mechanical advantage of feathering the oars?

14. A plummet, the string being held in the hand, is immersed in a current of water, and the string ultimately settles in a somewhat slanting

position. Explain by a diagram the nature and action of the forces which determine the position of the string.

15. If while a steamer is steaming along the smoke rises vertically, what conclusion can you draw as to the state of the atmosphere?

16. Give some instances of the practical application of centrifugal force.

17. How is it that a circus rider always leans towards the centre of the circus? If he increases his speed, does he lean more, or less, than he did before?

18. When a man, standing on a horse, which is going at great speed, jumps vertically upwards, what is the direction of the path which his body takes?

19. A ball is thrown vertically upwards, in an open railway waggon, travelling at high speed. What is the general appearance of its path to a person who sees this as the train passes by?

20. When a circus rider jumps through a hoop, in what direction does he spring?

21. In the rotation of the vanes of a windmill, is the velocity of every point on the vane the same? If not, where is it greatest?

22. Explain why and under what circumstances drops of water fly from the surface of a grindstone which is being rapidly turned.

23. Explain why and in what direction drops of water fly from the wheels of a carriage running along a wet road.

24. How is corn separated from chaff in a mill?

25. Account for the fact that it is as easy to play ball on a rapidly moving steamer as it is on land.

26. If at the equator a straight hollow tube were thrust vertically down towards the centre of the earth, and a heavy body were dropped through the centre of this tube, it would soon strike one side. Find which, and give a reason for your reply.

27. If a ball is allowed to drop from the top of a high tower, in what position does it fall in reference to the base of the tower?

28. If two porters, A and B, carry a cask hung to a pole resting on their shoulders, what is the proportion which each porter bears—

(*a*) When the cask is half-way between them;
(*b*) When it is at a distance from A twice that which it is from B;
(*c*) When it is at four times as far from B as it is from A;

29. Why is a finger caught in the hinge of a shutting door so severely crushed?

30. Explain the mechanical advantages of steel nippers in drawing nails from wood.

31. Apply the principle of the lever to explain the cracking of a nut by the teeth.

32. In lifting a weight with the hand, show that the lower part of the arm becomes a lever of the third kind.

33. What is the difference between gravitation and gravity?

34. How can you ascertain whether a table is quite horizontal, and whether a wall is quite vertical?

35. Why is it easier for a man to carry a pail of water in each hand than to carry only one?

36. A cart laden with stones may go safely on a road, one side of which is higher than the other; whereas if it were loaded with hay it might be overturned. Explain this.

37. Why are lamps and candlesticks loaded with weights at the base?

38. How can a body be accurately weighed by means of a balance which is not itself accurate?

39. Why are stepped stairs used in houses instead of a smooth inclined plane?

40. What do we understand by the length of the pendulum in an ordinary clock?

41. How is the ordinary pendulum regulated?

42. What alteration must be made in the length of a seconds pendulum which swings correctly at the sea-level, if it is to be brought to the top of a hill?

43. Explain the manner in which the oscillations of the pendulum may be applied to determining the figure of the earth.

44. What is the difference between cohesion and chemical affinity? What the difference between adhesion and chemical affinity?

45. What is the difference between cohesion and adhesion?

46. Give some illustrations of phenomena in which the forces of cohesion, of adhesion, and chemical affinity come respectively into play.

47. Mention some substances which have, in a pre-eminent degree, severally the properties of hardness; of malleability; of elasticity; and of brittleness.

48. Describe the construction and explain the action of the humming top.

49. Explain the nature of the mechanical operations which a labourer performs in digging earth with a spade and throwing it into a barrow.

50. Why must ships without cargo take ballast on board?

51. What is it that is weighed by an ordinary pair of scales?

52. In what sense are we to understand the statement that the spring balance indicates the true weight of a body?

53. With a horizontal wind a kite ascends. Draw a diagram showing the action of the forces by which it is urged upwards.

II.—ON LIQUIDS.

1. When a stream of water falls into a basin, drops spurt out; of what property of water is this a consequence and a proof?

2. What is the essential difference between liquids and gases?

3. Is a flood-gate which keeps the sea out of a dock exposed to more or to less pressure than one which keeps out a lake or river? The depth below the surface of the water is supposed to be the same in each case.

4. Under what conditions does the principle of the equality of pressures of liquids in communicating vessels no longer hold?

5. Illustrate and explain some of the principal phenomena of capillary attraction. What forms do the surfaces of mercury and of water assume in narrow tubes?

6. If one end of a skein of silk be placed in a liquid contained in a vessel, and the other hangs over the side, the liquid is found after some time to be empty. How may this have been brought about?

7. Describe experiments showing the porosity and elasticity of solids, and also of liquids.

8. Describe an experiment which shows that different liquids adhere to solids with varying degrees of force.

9. What are the causes which prevent a jet of water from reaching the height of the water in the reservoir from which it is fed?

10. Why can water-spiders and many other insects run on the surface of the water?

11. In pouring water out of a jug, why is some apt to trickle down below the spout?

12. Why is writing with ink more permanent than with lead pencil?

13. Describe a simple method of determining the exact volume of any body of irregular shape; a stone, for example.

14. A small cubical box full of water is placed on a large piece of cork which is floated on water. Explain what happens when a hole is made in one side of the box.

15. What metals float on mercury? what metals sink?

16. If a pipe from a gutter fits water-tight into the top of a water-butt, what pressure must be allowed for on the bottom of the butt?

III.—ON GASES.

1. What is the main distinction between gases and liquids?

2. Why is atmospheric air chosen as the type of gaseous bodies?

3. How can you prove the existence of an atmosphere?

4. Describe and explain the action of some apparatus which depend on the pressure of the atmosphere.

5. How is the pressure of the atmosphere measured?

6. How can you show that gases have weight; elasticity?

7. Demonstrate experimentally the elasticity of air.

8. What experiment proves that the atmospheric pressure at any given level is transmitted equally and in all directions?

9. How can you tell whether the Torricellian vacuum of a barometer is perfectly free from air?

10. Explain how the amount of the atmospheric pressure in pounds is found; and why we are unconscious of its action on our bodies.

11. Is it necessary that a barometer tube be everywhere of the same diameter? Must a thermometer tube have the same calibre throughout? Give reasons for your answers.

12. Explain the principle of the application of the barometer to the measurement of the heights of mountains.

13. Explain the principle of the use of the barometer as an indicator of the state of the weather.

14. Explain the manner in which water is raised in a pipette or in a wine-taster.

15. How do you measure the degree of rarefaction in a receiver attached to an air-pump?

16. Why does a bubble of air liberated at a considerable depth in water gradually increase in size until it reaches the surface?

17. Supposing an air-tight bladder, containing a cubic foot of air, at a depth of about thirty feet in the sea, to be brought to the surface, what would it measure then?

18. If a pound of atmospheric air under the ordinary atmospheric pressure measures 13·07 cubic feet, what will it measure under a pressure of 29·2 inches?

19. What is the main circumstance which limits the depths to which divers can go?

20. If a barometer were carried down in a diving-bell, what would take place? Give a rough quantitative result.

21. Empty and tightly corked soda-water bottles sunk to great depths in the sea, when they are brought up are often found to contain water, but are still tightly corked. To what may this be due?

22. Explain the use and action of a vent-peg in a beer-barrel.

23. Explain the action of the syphon. Does it act in a vacuum?

24. Explain why a body weighs less in air than in an exhausted receiver.

25. In selling diamonds by weight is it advantageous to the seller that the barometer should be high or low?

26. Is it advantageous to the buyer, that in buying diamonds the weight should be of rock crystal or of platinum?

27. How can an aeronaut make his balloon ascend or descend at pleasure?

28. Explain why, when the nozzle and valve-hole of a pair of bellows are stopped, it is difficult to separate the boards.

29. How do you explain the peculiar smell noticed after a shower of rain has fallen on a dusty road?

30. The parts of a whitewashed ceiling immediately under the rafters are lighter in colour than the rest. Account for this.

31. Why is the pressure in an ordinary closed room the same as the pressure in the open air?

32. How would you determine by experiment the volume of air contained in a porous material, such as a brick?

IV.—SOUND.

1. Describe an experiment which proves that sound cannot pass through a vacuum.

2. Describe the construction and explain the action of the safety whistle in steam-engines.

3. How can the velocity of sound be determined in gases, and how in liquids?

4. Mention some reason for thinking that high and low sounds travel with the same velocity.

5. What are the proofs that water conducts sound?

6. A shot is seen to be fired at some distance from the observer; between seeing the flash and hearing the report he counts 8 beats of the pulse (80 in a minute)—what is the distance of the gun?—*Ans.* About a mile and a quarter.

7. A flash of lightning is observed and the thunder is not heard until fifteen seconds afterwards. Why is this, and what is the distance of the observer from the flash?

8. What reasons have you for thinking that solid bodies conduct sound better than gases?

9. How is it that the sounds of telegraph wires are heard more distinctly when you put your ear to the telegraph posts?

10. A material, which can only be used in thicknesses of a quarter of an inch, is to be used for the purpose of stopping sound. What experiments could you make with such materials to enable you to select the best?

11. Arrange a few substances in the order in which they transmit sound.

12. Supposing you wish to exclude sound from a room, what principle do you act upon?

13. How is it that you hear a sound originating to windward better than one which arises to leeward of you?

14. Why is the sound of a tuning-fork stronger when it is placed on a table or on a box?

15. Explain the difference between the intensity and the pitch of sounds, and point out the causes which affect the intensity.

16. Describe the siren, and explain how the number of vibrations per second in a note of given pitch may be found by means of it.

17. Why is the pitch of women's and of boys' voices higher than that of men's?

18. What is resonance? How is it most effectually prevented in enclosed spaces?

19. How distant must a wall be in order that it may echo a word of four syllables?

20. The sound of a gun is echoed from a mountain half a mile off—at what time will the echo reach the person who fires the gun?

21. What experimental evidence would you give that sound can be refracted?

22. A boy holds a stick tightly in a slanting position against some vertical iron railings, which are four inches apart—at what rate must he run so as to produce a note with sixteen vibrations in a second?

23. How would you determine the rate of vibration of a tuning-fork?

24. Explain how to construct an instrument with strings of the same material and thickness, so that, under the same tension, the successive strings may give the consecutive notes of the major scale.

25. Four strings of the same material and length, but of different thicknesses, are stretched on a violin and tuned so as to give successive fifths; compare the thicknesses of the several strings.

26. Two tuning-forks at the same temperature vibrate at the same rate. One of them is heated. State and explain the effects produced when the forks are now sounded together.

27. A jar containing air, and another containing hydrogen, resound to the same tuning-fork. Are the jars alike? If not, state and explain the difference between them

28. Why is sound heard to a greater distance over the sea than on land?

29. What would be the general nature of the difference between two tuning-forks of the same dimensions, one of brass, and the other of steel?

30. What note makes three times, and what note one-third as many vibrations as the fundamental note C?

31. A glass of effervescing wine does not resound when struck until all the carbonic acid has escaped. Explain this.

32. A person claps his hands in front of a wall, and hears the echo a quarter of a second afterwards. At what distance is he from the wall?

V.—HEAT.

1. *How does heat generally affect the size of bodies? Are there any exceptions to the general rule?*

2. *In what way is the heat of the human body generated and kept up?*

3. Describe the general effects of heat upon solids, liquids, and gases.

4. Describe the way in which an ordinary mercurial thermometer is made and graduated.

5. How do you proceed to examine whether a thermometer is accurate or not?

6. Compare the advantages and disadvantages of alcohol and water for thermometers.

7. State any considerations, or describe an experiment, which shows that heat is propagated in a vacuum.

8. A square foot and a square inch at different distances from the source of heat receive from this source the same total quantity by radiation. What are their relative distances from the source?

9. How can you prove experimentally that the intensity of radiant heat received by a body diminishes inversely as its distance from the source of heat?

10. Point out the difficulties which attend the determination of the actual temperature of the air, as distinct from that of surrounding objects at any time and place, and how errors in the determination may be best avoided.

11. How do you establish the fact that there are different kinds of heat, as there are different kinds of light?

12. In what respect does the manner in which heat is diffused through liquids and through gases differ from that in which it is diffused through solids?

13. In what respects are thatched roofs preferable to those of slate or tiles?

14. How is it that a room with a glass roof, but not heated artificially, becomes much hotter in summer than the outer air?

15. What is the real scientific meaning of the term warm clothing?

16. Describe and explain the gridiron pendulum.

17. Why does a pianoforte get out of tune when brought into a cold room? Is the pitch higher or lower?

18. If a balloon pass from a cloud into sunshine, what danger is likely to ensue if the balloon be not well managed, and what is the cause of it?

19. A certain volume of air, at the temperature of the melting-point of ice, and under the ordinary atmospheric pressure, is contained in a vessel, the pressure on which may be varied. What pressure must be applied in order that, when the temperature of the enclosed air has been raised to that of the boiling-point of water, the volume of the air should remain constant?

20. Give some account of the way in which winds are produced.

21. Give an instance of a great mechanical force exerted by the passage of a liquid from the liquid to a solid state.

22. Mention some substances which are lighter in the solid state than in the liquid state.

23. What metals are suitable for taking sharp casts, and what are not suitable? Give a reason.

24. Compare ether and water, alcohol and linseed oil, camphor and ice, as regards their evaporation.

25. What important part does the great latent heat of water play in the general economy of nature?

26. What is the difference between gases and vapours?

27. Distinguish between a cloud and vapour.

28. Give a reason for the crackling of wood in fires.

29. Explain the singing of a tea-kettle.

30 Mention some substances which pass at once from the solid into the gaseous state.

31. Account for the fact that moist clothes dry upon being exposed to the open air at freezing temperature.

32. Define precisely what is meant by the expression, that the boiling-point of water is 100° C.

33. Point out, and demonstrate experimentally, how the boiling point of a liquid may be made to vary.

34. Explain how the height of a place may be found by the temperature at which water boils there. If you had only salt water, would that do for this determination?

35. Why cannot meat be properly boiled on the top of high mountains by the ordinary method?

36. What are the several results observed upon continuing the application of heat to a vessel containing ice, of a temperature of 0° C., until the contents of the vessel are raised to 100° C.; and what occurs if the application of heat be continued further?

37. Describe fully the changes which take place when a cubic foot of ice originally at a temperature of —10° C. is continuously heated.

38. When a volatile liquid, such as ether, is dropped on the hand, cold is felt. What is the reason of this?

39. Explain fully the feeling of freshness produced by watering streets.

40. How is it that an island climate is more moderate than a continental one in the same latitude?

41. Illustrate what is understood by the terms *latent heat*, *sensible heat*, *specific heat*. Can you describe some particular method of determining the specific heat of a body?

42. Explain the formation of dew and of hoar frost.

43. On what substances does dew form most freely? Why is none formed under trees?

44. When the steam from a locomotive is seen only slowly to disappear. what conclusion can be drawn as to the state of the atmosphere?

45. State what is understood by the *hygrometric state* of the air; and describe the construction and use of some form of hygrometer.

46. What phenomena are observed when a vessel containing ice or snow is brought into a warm room?

47. Why is dew more abundant on a still, clear night than on a windy or cloudy night?

48. Explain the following phenomena: (*a*) the moisture on inside walls when a thaw sets in; (*b*) the cloud produced in the receiver of an air-pump when the air is suddenly rarefied; (*c*) the cold experienced on standing near a wall of ice.

49. Define the dew-point. The dew-point is oftener much higher in summer than in winter, and at the same time the air is drier; how do you account for that? Why is dew seen usually near the ground only, and not so much a few feet above the ground, and on some bodies more than on others?

50. The surface of a pond is observed, under certain atmospheric conditions, to be covered with clouds of vapour. Under what circumstances does this occur; and how do you account for the phenomenon?

51. If a stream of air issuing from a bag which is pressed by a weight impinge on the face of a thermopile, indications of heat appear; but if the

stream issue from an air-gun receiver, into which air had previously been compressed, indications of cold appear : account for these facts on general principles, and give some other illustration of the same principles.

52. What are the chief points on which depends the climate of any particular place?

53. Give some illustrations of the principle that whenever any of the effects which heat can produce are reversed, heat itself is the result.

54. Explain the principle of the barometer. How is it affected by variations of temperature? Why would a water-barometer be more affected by such variations than a mercurial one?

55. Illustrate the principle that, whenever any of the effects which heat can produce are brought about in any other way, cold is the result.

56. By what means could you produce ice artificially without the aid of a freezing mixture?

57. Describe the physical constitution of a cloud, and explain why it remains suspended in the air. A change of wind from NE. to SW., or *vice versâ*, is, in this country, almost always accompanied by rain. Give a rational explanation of this.

58. Give some instances of the production of heat by friction, by percussion, and by pressure.

59. Explain the way in which rain is produced, from the beginning of its formation to the end.

60. Supposing we had no coal and no wood, what sources of heat would still be available to us?

61. What are the two causes which enable us to attain a high speed on railways as compared with horse power on ordinary roads?

62. Independently of direct measurements, what means of measuring the heights of places do we possess?

63. The rays of the sun in passing through a window do not perceptibly heat the panes of glass, but if a glass screen be held in front of the fire it soon becomes visibly warm. Give the reason of this.

64. Why is heavy rain injurious to ripe grapes?

65. An earthenware tile, which seen by daylight has a dark pattern on a white ground, is heated to a white heat and viewed as it cools in a dimly lighted room. Explain the appearances it presents as it cools.

66. When the sun's rays have passed through a thick glass plate they will not affect the bulb of an ordinary thermometer, but will act upon a blackened one. Explain this.

67. Why does a thermometer rise higher when the sun shines on a wall near it?

68. Why do grapes ripen better against a wall than in the open; why better against a dark wall than against a white one?

69. The upper surface of a laurel leaf is bright and smooth, the lower surface rough. What effect has this on the temperature?

70. On one side of a plate of rock salt is a delicate thermometer; on the other side a plate of rock salt, and one of iron, both at the same high temperature, are successively placed in front of the plate. How is the thermometer affected thereby in each case?

71. What effect has the opening of a soda-water bottle on the temperature of the liquid?

72. Why is the evaporation from wet grass greater than that from an equal surface of water at the same temperature?

73. Mention some reason, based on experiment, for supposing that the bore of a cannon does or does not increase by heat.

74. At what temperature would the velocity of sound in carbonic acid by the same as that in air at zero?

75. If water be kept still it may be raised to above 100° C. even in the open air. If shaken it will burst into ebullition. Explain why only a comparatively small amount is turned into steam?

VI.—LIGHT.

1. What analogies and what differences are there between sound and light?

2. Why does a bird at some height in the air cast no shadow on a sunny day?

3. What determines the size of a shadow?

4. Describe a method by which the velocity of light may be determined.

5. Describe and explain any arrangement for determining the relative strength of two sources of light.

6. A candle is held near a window: on looking at it a little obliquely two images of the candle are seen. How are these produced?

7. How can you determine by an optical method the thickness of a glass mirror?

8. Account for the fact that a coin placed in water appears higher than it really is, and that shallow lakes appear shallower than they really are.

9. Show by a diagram the manner in which a stick appears bent when placed obliquely in water. Explain the appearance.

10. The eye being held in such a position that a coin at the bottom of a basin is invisible, pouring water in, it comes into view: supposing, instead of water, a liquid with a greater refractive index is poured in, must the height of the liquid be greater or less than that of the water?

11. Standing in front of either end of an aquarium tank, if you look at the other the back appears nearer; standing in front of the middle of the tank the back appears curved. Account for these results.

12. In spearing salmon what should be the direction of the aim?

13. Illicit stills have sometimes been discovered by the column of heated air arising from them. How may this be accounted for?

14. How can you determine the focal length of a double convex lens?

15. What is a *virtual* image? what a *real* one?

16. What simple experiment made with a lens would tell you whether it was an achromatic one?

17. What is short sight, and what long sight? Show the use of spectacles in remedying these defects.

18. *Why is short sight usually met with in young and long sight in older persons?*

19. Describe and explain the camera-obscura.

20. What are the practical difficulties which limit the magnifying power of the telescope?

21. A short-sighted person uses an opera glass which has just been adjusted for long sight. Does he need to alter it? and if so, how?

22. How is the ordinary sight of a person under water affected? Is he short-sighted or the reverse?

23. Is there any general difference in the structure of the eyes of fishes from those of o her animals?

24. Why do the more distant trees in an alley seem to run together?

25. There is a photographic rule that in photographing a building the nearer you are to the building the longer must be the exposure. On what is this rule based?

26. Suppose five similar candles to burn in a cluster at one end of a rod 10 feet long, and two similar candles at the other end. How far from the cluster of five must a sheet of paper be placed so that the illumination on one of its sides is equal to that on the other?

27. Trace and explain the appearance of and the course of a ray of light from the visible setting sun to the observer, giving a diagram.

28. What appearance does a piece of red sealing-wax present in a room lighted by a pure yellow light?

29. What colours would appear black in a room in which the sun's light is admitted through red glass?

30. If two pieces of the same grey paper be laid, the one upon a black and the other upon a white ground, the former appears lighter. Give an explanation of this.

31. If powdered glass be soaked with an oil of the same refractive index, the individual particles cannot be seen. Explain this.

32. Under what circumstances would a colourless mineral be invisible in a liquid?

33. Account for the transparency of paper which has been soaked in oil.

34. Why does the surface of a table appear brighter when a lamp is surrounded by an opaque globe?

35. How is it that an unknown object appears larger in a mist than it really is?

36. Explain why it is that whatever be the shape of a small aperture in the wall of a dark room, the image of the sun formed there will be round.

37. If unpolished, colourless precious stones are opaque in consequence of their surfaces being rough, how may they be easily made transparent so that internal flaws can be discovered?

38. If you can just see to read by moonlight, and also by a candle five yards off, how much brighter is the moon than the candle? Distance of the moon, 240,000 miles.

39. If some black lines are ruled on white paper, and one half covered with a thick piece of plate glass, what effect does an observer perceive when the lines are looked at?

40. Why is moist air more transparent than dry air?

41. Why does ordinary daylight appear dazzling on coming from a dark room?

42. In what direction does an eye under water see an object above the water?

43. You have two achromatic convergent lenses of 1 inch and 10 inches focal length respectively. How would you combine them to form (*a*) a compound microscope; (*b*) a telescope? Give diagrams showing the action of the lenses in each case.

44. Writing in ink in a particular illumination can be seen in whatever position it is looked at; but writing in pencil only when looked at in certain positions. Explain this.

VII.—MAGNETISM.

1. The earth attracts a falling stone; a magnet attracts a piece of soft iron. In what respects do these attractions agree, and in what respects do they differ?

2. In what sense is it true that magnets only attract magnets?

3. How may it arise that in some cases attraction takes place between the like poles of two magnets?

4. If a piece of hard steel wire (unmagnetised) and a similar piece of soft iron wire be presented to one pole of a magnet, state which you would expect to be attracted with the greater force, and give your reason.

5. Five balls of iron hang in a series from the north end of a magnet, but you cannot get a sixth ball to hang: why? The north end of a second magnet is brought directly *over* that of the first; seven balls of iron now cling together: why? You place the second north pole *below* the series of balls; several of them fall away: explain this.

6. Describe a dipping needle. How does it behave when the instrument is placed out of the magnetic meridian? How far is the action of the earth on a freely suspended needle similar to that of a large magnet?

7. A magnetic dipping needle is moved completely round the earth, passing through the two poles; describe the changes in its position which take place during this operation.

8. State how you would magnetise a piece of watch-spring.

9. A steel needle, held vertically and struck with a hammer, becomes magnetised: how do you account for this? How does the position and the striking affect the case? Which will be the north pole of the needle?

10. How is it that iron tools, such as chisels, &c., are often found to be permanently magnetised?

11. What is meant by the terms 'magnetic saturation' and 'magnetic limit'?

12. Point out the errors most likely to affect the determination of the bearings of a gallery of a mine by means of a compass.

13. What is the magnetic condition of a bar of soft iron held parallel and near to a bar magnet?

14. By what experiments could you ascertain whether a sewing needle is or is not slightly magnetised?

15. Why is less force required to pull a small iron rod away from the poles of a powerful horseshoe magnet than would be required to pull a thick bar of iron away from the poles of the same magnet?

16. Give your reasons for supposing that there is no such phenomenon as magnetic conduction.

17. State the experiments, and the reasoning from which it is inferred that the earth is a magnet.

18. The ends of a bar magnet have the property of attracting iron, but between them there is a part where this property is entirely absent. If a magnet is broken across at the neutral part, what are the properties of the two pieces?

19. Two pieces of magnetised sewing needles are fastened to corks so as to float horizontally on water. What takes place if the needles are left to themselves at a distance of a few inches apart on the surface of the water?

20. A piece of steel is hung from one end of a delicate pair of scales, and is accurately counterpoised. It is then magnetised. Does this cause the scale beam to incline in either direction?

21. What effects have a moderate, and what effects an extreme change of temperature, on a magnetised steel bar?

22. Describe the manner in which the magnetic needle is used to trace, in any place, a line due North and South.

VIII.—FRICTIONAL ELECTRICITY.

1. How can you prove that whenever one kind of electricity is produced the other is produced at the same time and in the same quantity?

2. What kinds of electricity are produced on each of the following substances when they are rubbed together in pairs? Flannel and brass, glass and flannel, gun-cotton and shellac.

3. How do you prove that there are two kinds of electricity?

4. If you were given a stone, and you were unaware whether it were a conductor, explain how you would proceed to determine this point.

5. Why is repulsion a surer test of the electric condition of a body than attraction?

6. Give some instances of the influence of moisture in electrical phenomena.

7. What is the best means of depriving a bad conductor of a charge of electricity?

8. State the general laws of distribution of electricity on an electrified conductor. Describe the distribution in the case of a hollow tin tube insulated and electrified. How is it modified if you approach your hand to one end?

9. How can you prove that electricity only resides on the surface of bodies?

10. By what experiment can you prove that a solid sphere of metal cannot be more highly electrified than a hollow shell of the same diameter?

11. A body (A) is brought near a magnetic needle, which is thereby seen to be acted upon. How could you prove whether this action is due to electricity or to magnetism?

12. In what respect do the forces of magnetism and electricity resemble each other? In what do they differ?

13. Explain the statement that electricity only attracts electrified bodies.

14. An egg-shell is placed upon a table, and a stick of sealing-wax rubbed with flannel is brought near it. As the sealing-wax is moved the egg follows it. Give a full explanation of these results.

15. Sulphur is ground in a porcelain mortar, and some of the powder is placed on the cap of a gold-leaf electroscope; the leaves diverge: why?

The powder is removed by just tilting the electroscope. What happens to the leaves?

16. If you were provided with a body charged with positive electricity, and were required to charge a plate of metal with negative electricity by means of it, how would you proceed?

17. Explain why it is in general easier to impart a charge of electricity, to a bar of iron by induction, and to a piece of india-rubber by friction, than *vice versâ.*

18. What is meant when it is said that the earth is the common reservoir of electricity?

19. How can heat be converted into electricity?

20. The bared end of a long insulated wire being given to you, you are required to determine whether it is charged with electricity, and if so, with what kind of electricity.

21. If an electrified body be placed in communication with the earth, or have a sharp point projecting from it, in either case all sign of electricity soon disappears. Explain why this is so, by referring to the general laws of distribution of electricity.

22. Explain the use of the prime conductor of a machine. You can draw brighter but not longer sparks by using a large conductor than by using a small one: explain why that is so.

23. It is required to compare the insulating power, under water, of two materials, such as gutta-percha and india-rubber. Explain how this may be done.

24. Describe the mode of charging and discharging a Leyden jar. What circumstances influence the amount of electrical charge which such a jar can acquire?

25. Give an explanation of thunder and lightning, embracing the phenomenon known as the return shock.

26. Would you expect a gold-leaf electroscope to show signs of excitement, (1) in doors, (2) out of doors, when there is a thunder-cloud overhead? What sort of effects would you expect in such a case, and how caused?

27. A gold-leaf electroscope, connected with the ground by a wire, is placed near the prime conductor of a powerful electrical machine in action. Whenever a spark is taken from the machine the leaves suddenly diverge. Explain this.

28. The following substances being given, you are required by their aid

to construct and work an electrophorus. Tinfoil, brown paper, india-rubber, and sealing wax.

29. Describe some method of collecting and examining the electricity of the atmosphere.

30. What is a lightning-conductor? and in what way does it act? Suppose you are required to extemporise one for a detached house, give a detailed account of the manner in which you would proceed.

31. If a lightning-conductor on a building be carried near a part of the roof covered with lead, why is it desirable that the lead should be connected with the conductor?

32. A shallow tea-tray in which are placed some pith balls is placed on a non-conductor and is then electrified. Explain what takes place when the tray is lifted up by an insulating handle.

33. You have several rods of unknown materials. Describe exactly experiments which would enable you to distinguish those of them which are conductors of electricity from those which are non-conductors.

34. Could an electrical machine be made to act if it had a metal plate instead of a glass plate? If not, why not? If it could, show how.

35. Describe experiments which show that the terms *vitreous* electricity and *resinous* electricity are inappropriate.

36. A bird in a metal cage hung by an insulating cord is unaffected however strongly the cage may be electrified. Show what risk the bird would run on quitting the strongly charged cage.

37. If an insulated tin tube be charged, what difference of tension will there be at different parts, both inside and outside the tube?

38. A Leyden jar is placed on an insulated stand, and is connected with an electrical machine at work; its outer coating is connected with the ground by a wire; state and explain what happens in this wire.

39. A man wearing a silk sock warms his foot at the fire, and rubs the sock with his dry hand. He then suddenly pulls it off. State and explain what happens to the sock.

40. Account for the fact that we may have lightning discharges without thunder.

41. A small piece of gold-leaf is brought near the knob of a charged Leyden jar, and is seen to hover about it. Account for this fact.

42. Show that a cloud charged with a particular kind of electricity may interfere with the signalling on a telegraph wire.

43. If a tall iron rod projecting above the roof of a house be not connected with the ground, but passes near an iron rod which is so connected, sparks are sometimes seen to pass between the rod and the pipe even when there is no lightning. Explain this.

44. A small insulated electrified sphere is placed at a certain distance from an electroscope. How is the original action on the electroscope affected by separately interposing between it and the sphere, (*a*) an ebonite plate, (*b*) an insulated brass plate, (*c*) an uninsulated brass plate?

45. A small ball suspended by a silk thread is placed inside, but no touching, an insulated tin cylinder. The outside of this is then electrified. State and explain the electrical condition of the ball when removed from the inside of the cylinder.

46. If a Leyden battery is discharged through a number of persons forming a chain, do all receive an equal shock? If not, where and why is it strongest.

47. An orange is placed in a dry wineglass, and a needle is inserted in it. State and explain the electrical condition of the orange after a shellac rod rubbed with flannel has been held in front of the point.

48. The experiment is repeated, but the rod is held in front of the orange away from the point. Explain this.

49. If the electricity of the earth is negative, what is the electrical condition of falling rain or of ascending smoke?

50. A sheet of brown paper is dried and smartly rubbed with india-rubber. Explain what takes place when it is placed against the walls of a room.

51. A soap bubble is blown on the end of an insulated conducting tube; will any change take place if the conductor is electrified?

52. What is the probable electrical condition of a person wearing racket shoes and playing rackets in a covered court in dry weather?

53. Two equal metal balls are electrified, one five times as strongly as the other. When at a certain distance apart, they are found to repel one another with a force equal to the weight of one grain. If they are brought into contact and then separated to the same distance as before, what force will they exert on each other?

54. On bringing the finger near the knob of charged gold-leaf electroscope, the divergence of the leaves is seen to diminish. Explain this.

IX.—VOLTAIC ELECTRICITY.

1. A plate of pure zinc is partially immersed in dilute sulphuric acid: what is its electrical state? A plate of copper is also partially immersed in the same liquid: what is its state? The plates are now connected outside the liquid by a wire. State and explain fully what ensues.

2. What are the conditions for the production of a voltaic current? Mention some different arrangements in which these conditions are fulfilled.

3. By what experiments can you prove that the electricity of a voltaic cell and that of a frictional electrical machine are the same in kind?

4. What are the chief points of difference between statical and dynamical electricity?

5. A wire traversed by an electrical current is placed over and then under a magnetic needle. Describe the effects that are thereby produced.

6. By what means would you ascertain the direction of a current of electricity in a wire the ends of which are hidden from you?

7. Give some instances of accidental voltaic actions.

8. When is a voltaic circuit said to be *open*, and when *closed*?

9. Explain the meaning of the terms 'direction of the current,' 'electromotive force,' 'electromotive series,' 'positive electrode,' and 'negative plate.'

10. Give two examples of the chemical action of an electric current, and two others of the magnetic action of the same current.

11. A small magnetic needle is feebly magnetised: it is desired to remagnetise it in such a manner that its original polarity is reversed. Describe how you would proceed to do this by means of a voltaic current.

12. What is essential in the construction of an electromagnet? Upon what circumstances does the magnetic intensity of such an instrument depend? and on what does the facility of magnetising and demagnetising depend? Show why a thick wire is best for such an instrument.

13. You are required to coil a wire, and then to suspend it so that the axis of the coil, when a voltaic current is sent through it, shall set like a magnetic needle in the magnetic meridian. Show by a sketch how this is to be done.

14. If the earth's magnetism were due to electric currents on its surface,

show in what directions they must flow in order to produce the effects observed.

15. You are required to describe distinctly how you would obtain (*a*) a current of frictional electricity; (*b*) a current of voltaic electricity; (*c*) one of thermoelectricity; (*d*) an induced current by means of a permanent magnet.

16. Describe an experiment which proves that electric currents flowing in the same direction attract each other, while currents flowing in opposite directions repel each other.

17. A current passing through a long wire is so weak that when the wire is stretched over and parallel to a suspended magnetic needle the needle is not perceptibly affected. Describe, and explain an arrangement which would enable you to obtain a movement of the needle by the action of the current.

18. A metal ring through which a current circulates can move horizontally, its plane remaining vertical. Describe, and explain what happens when one pole or the other of a bar magnet is presented to the ring.

19. Describe some experiment to prove that, when the terminals of a voltaic battery are connected by a wire, the liquid in the battery itself is traversed by an electric current.

20. Describe an arrangement for making a ring traversed by a current float on water. In what way will it set if left to itself? and state what takes place according as one or the other pole of a magnet is presented to it.

21. A strip of gold leaf attached to two metal conductors hangs somewhat loosely in a vertical position between the two poles of a horseshoe magnet. When a current of electricity is passed through the gold leaf, what takes place?

22. What are the essentials for establishing electrical telegraphic communication between two places?

23. How would you compare two wires as regards their power of conducting electricity?

24. Two metals being given, you are required to determine experimentally their place in the electromotive series. State what apparatus you would require for the experiments, and how you would make them.

25. How can you prove experimentally that in a closed voltaic circuit the strength of the current is everywhere the same?

26. A bar of copper weighing one pound is drawn into wire of a certain length; two pounds of the same kind of copper are drawn into

wire of four times the length. What is the ratio of the total resistances of the two wires?

27. A voltaic couple is closed by a wire 84 feet in length; after the circuit is opened one third of the wire is bent upon itself, so that the two parts are in contact; and the circuit is again closed by the wire thus modified. What is the ratio of the resistance of the wires in the two cases?

28. What would be the relative resistances of two wires of the same material, one of which was three times as long, but only half as heavy as the other?

29. What would be the general nature of the effects produced by a complete break in a telegraph line on the signals of the sending and on those of the receiving station? What in like manner would be the effect of a leak?

30. If at a place where the declination is easterly there be an earth current from east to west, what effect will it have on a compass needle?

31. Two large insulated flat brass plates are set facing each other and very near together. A wire from one of them is joined to the zinc end of a battery of a great many cells; and a wire from the other plate is joined to the other end (copper or platinum) of the battery. Without touching either the wires or plates with conductors, the wires are removed from the plates, and the plates then moved to a distance from each other. What will now be the electrical condition of each plate?

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